Lethbridge Wind Research Test Site

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LETHBRIDGE WIND RESEARCH TEST SITE

EVALUATION OF WIND & SOLAR PUMPING SYSTEMS

1985 - 1987

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EXECUTIVE SUMMARY

Since the Lethbridge Wind Research Test Site was established in 1982, considerable interest has occurred in the use of wind and solar systems by manufacturers of solar and wind pumping systems, the general public and representatives of various overseas countries. Although it was initially set up to evaluate and demonstrate relatively small water pumping wind turbines for local agricultural drainage applications, the Test Site has diversified and now includes solar pumping systems and larger wind turbines capable of meeting export market needs for developing country applications.

This report presents the results of the testing carried out over the past three years at the Lethbridge Wind Research Test Site. During this period, a total of eight wind turbines and two solar systems were monitored and evaluated at the Test Site. The Site operates continuously each year from May until freeze-up in mid-October. Each manufacturer is responsible for installation and maintenance of their unit(s), in order to realistically evaluate reliability and availability factors for each machine tested.

The results of this study have been very encouraging. It is apparent that the wind industry in Canada is maturing, with manufacturers becoming more cognizant of the need for product reliability as well as performance curves. There is growing interest by potential users, both domestically and internationally, to utilize wind and solar pumping systems for a variety of applications. A one-day workshop was held in Lethbridge in 1987 to evaluate the market potential of wind and solar pumping systems. This workshop was very successful in bringing manufacturers and potential users together to determine current status of the wind and solar industry and the needs of the potential users of this technology.

Long term machine reliability is the key factor which all manufacturers must strive to improve if successful development of this industry is to occur. This has proven to be of much greater importance than overall performance numbers or improvements. The availability of water pumping systems tested at the site ranges from a low of 24 percent to a high of 100

percent. The testing program has shown that to fully measure the overall availability and reliability of a machine requires that it be monitored for at least two to three years. Most of the machines on the Test Site have not met this requirement because of the continuous changes and upgrading by the manufacturers. The exceptions to this are the two solar pumping systems. They have performed very reliably over the last three year test period, with very low maintenance requirements. Their disadvantage at present is a somewhat higher capital cost per cubic meter of water pumped compared with the wind turbines. However, this capital cost difference is decreasing rapidly and the solar systems are expected to be very competitive for smaller pumping applications (e.g. cattle watering) in the near future.

The export potential for wind and solar pumping systems appears particularly good. Since the data obtained from the Test Site is based on the International Energy Agency's (IEA) wind turbine performance testing standard, extrapolation of the information world-wide is possible. Numerous reports and data sheets have been sent to representatives in overseas countries interested in possible application of Canadian turbines. One of the turbines on the Test Site and a hybrid of the two solar pumping systems have been exported for use in Barbados. This export of machines is expected to increase as overall reliability of wind turbines increases and costs of solar systems decrease.

The Lethbridge Wind Research Test Site is unique in Canada in the test program for wind and solar pumping systems. Interest in the test program continues to increase throughout the world. In Western Canada, most potential buyers of wind and solar pumpers visit the site before purchasing. The manufacturers of wind and solar pumping systems recognize the value of the independent testing program and are keenly interested in the test results. Continued operation of the test site is seen as a positive means of developing and improving Canada's wind and solar pumping industry.

TABLE OF CONTENTS

Page

PART I LOW HEAD PUMP TESTING AT THE LETHBRIDGE WIND RESEARCH TEST SITE

1.0 INTRODUCTION 1

2.0 SITE DESCRIPTION 3
- 2.1 Site Layout 3
- 2.2 Description of Pumping Systems 3
- 2.3 Instrumentation and Monitoring Equipment 6

3.0 ANALYSIS PROCEDURES 11
- 3.1 Performance Curves 11
- 3.2 System and Pump Efficiency Curves 14
- 3.3 Monthly Pumping Estimates 15

4.0 PRESENTATION AND DISCUSSION OF RESULTS 16
- 4.1 Performance Curves 16
  - 4.1.1 Wilks Cam 10
  - 4.1.2 Chinook 7.5
  - 4.1.3 Bowjons
  - 4.1.4 Deltx WP-20
  - 4.1.5 Maestro
  - 4.1.6 Whirlwind W4
  - 4.1.7 Windmotor
  - 4.1.8 Solar Pumpers
- 4.2 Mechanical Integrity 29
  - 4.2.1 Wilks Cam 10
  - 4.2.2 Chinook 7.5
  - 4.2.3 Bowjon Diaphragm
  - 4.2.4 Bowjon Air Lift
  - 4.2.5 Deltx WP-20
  - 4.2.6 Maestro
  - 4.2.7 Whirlwind W4
  - 4.2.8 Windmotor
  - 4.2.9 Environmental Systems Solar Pumper
  - 4.2.10 Campro Portable Solar Pumper
- 4.3 System and Pump Efficiency Curves 34
  - 4.3.1 Wilks Cam 10
  - 4.3.2 Chinook 7.5
  - 4.3.3 Bowjons
  - 4.3.4 Deltx WP-20
  - 4.3.5 Maestro
  - 4.3.6 Whirlwind W4
  - 4.3.7 Windmotor
  - 4.3.8 Solar Pumpers

TABLE OF CONTENTS (Cont'd):

		Page
4.4	Monthly Pumping Yields	43
	4.4.1 Chinook 7.5	
	4.4.2 Bowjon Diaphragm	
	4.4.3 Deltx WP-20	
	4.4.4 Whirlwind W4	
4.5	Optimization of Performance Curves for Peak Pumping Volume	48
PART II	**WELL SIMULATOR**	
5.0	INTRODUCTION	52
6.0	SIMULATOR DESCRIPTION	53
7.0	PRELIMINARY RESULTS	55
7.1	Wilks Cam 10	56
7.2	Whirlwind	56
PART III	**APPLICATIONS AND MARKETS FOR WIND PUMPS**	
8.0	INTRODUCTION	60
8.1	Land Drainage	60
8.2	Watering Livestock from Dugouts	60
8.3	Watering Livestock from Wells	62
8.4	Wetlands Development	65
8.5	Export Opportunities	65
9.0	ECONOMICS OF WINDPUMPING	66
10.0	CONSTRAINTS TO WINDPUMP DEVELOPMENTS	68
PART IV	**SUMMARY**	
11.0	IMPACT OF THE TEST SITE	71
11.1	Attracting New Industry	71
11.2	Export Market Development	71
11.3	Pump Development	71
12.0	CONCLUSIONS AND RECOMMENDATIONS	72
13.0	REFERENCES	73
	APPENDIX "A" - Pumping System Specifications	
	APPENDIX "B" - Performance Data and Raw Data Plots	
	APPENDIX "C" - Results from Pump Tests Performed by PAMI	

LIST OF TABLES

	Page
2.1 Pumping Systems Tested at the LWRTS	5
4.1 Record of Availability of Tested Water Pumping Systems	31

LIST OF FIGURES

		Page
2.1	Site Layout	4
2.2	Typical Pumping Circuit	7
2.3	Data Acquisition System	10
4.1	Wilks Cam Pumping Performance	18
4.2	Wilks Cam Rotor Performance	18
4.3	Chinook Pumping Performance	19
4.4	Chinook Rotor Performance	19
4.5	Bowjon Diaphragm Performance	21
4.6	Bowjon Air Lift Performance	21
4.7	Deltx WP-20 Pumping Performance	23
4.8	Deltx WP-20 Pump Speed	23
4.9	Maestro Performance	26
4.10	Whirlwind Performance	26
4.11	Windmotor Pumping Performance	28
4.12	Windmotor Rotor Performance	28
4.13	Performance of Solar Pumpers	30
4.14	Wilks Cam System Efficiency	36
4.15	Wilks Cam Pump Volumetric Efficiency	36
4.16	Chinook System Efficiency	37
4.17	Chinook Pump Volumetric Efficiency	37
4.18	Bowjon Diaphragm System Efficiency	39
4.19	Bowjon Air Lift System Efficiency	39
4.20	Deltx WP-20 System Efficiency	40
4.21	Deltx WP-20 Pump Volumetric Efficiency	40
4.22	Maestro System Efficiency	42
4.23	Whirlwind System Efficiency	42
4.24	Windmotor System Efficiency	44
4.25	Windmotor Pump Performance	44
4.26	Efficiency of Solar Pumpers	45
4.27	Chinook's Monthly Pumping Potential	47
4.28	Bowjon Diaphragm's Monthly Pumping Potential	47
4.29	Deltx WP-20's Monthly Pumping Potential	49
4.30	Whirlwind's Monthly Pumping Potential	49
4.31	Potential Changes to the Whirlwind's Performance	50
4.32	Effect of Changes on Monthly Pumping Potential	50
6.1	Design of Well Simulator	54
7.1	Wilks Cam Performance at 20 Metres Lift	58
7.2	Whirlwind Performance at 20 Metres Lift	59
8.1	Schematic Diagram of Windpump Application for Low-lift Tile Drainage Outlet	61
8.2	Schematic Diagram of Air Lift Pumping for Livestock Watering	63
8.3	Maximum Consecutive Periods of Calm for a Range of Cut-in Wind Speeds at Three Alberta Locations	64
8.4	Installation of Chinook 7.5 for Irrigation Pumping Demonstration - Barbados Agricultural Development	67
9.1	Comparison of Wind, Solar and Diesel Pumping Costs (World Bank, 1983)	69

I

LOW HEAD PUMP TESTING

LOW HEAD PUMP TESTING AT THE LETHBRIDGE WIND RESEARCH TEST SITE

1.0 INTRODUCTION

Wind energy was used extensively to pump water for agricultural applications in North America since the 1850's and reached peak usage near the turn of the 20th century. With the advent of electric power, the demand for wind turbines declined dramatically. However, with increasing energy costs during the 1970's, interest in using alternate energy again increased and farmers in particular began to look seriously at using wind energy for water pumping applications. In order to provide good technical and economic information regarding the potential use of wind energy in modern times, Alberta Agriculture initiated a program of testing and demonstrating commercially available wind turbines and solar systems for agricultural water pumping applications.

The two main objectives of the study have remained constant throughout the six years of operation and are:

1) Evaluate the potential for wind turbines to efficiently pump water for agricultural uses.
2) Monitor, demonstrate and evaluate various types of wind pumping equipment developed, manufactured or distributed in Alberta and Canada.

The Lethbridge Wind Research Test Site was initially set up in 1982 immediately east of the city of Lethbridge, Alberta. Since that time the Site has been managed and operated jointly by Alberta Agriculture, Jensen Engineering Ltd. (Olds, Alberta) and DRB Engineering Consultants Ltd. (Calgary, Alberta). Funding for the Test Site has been provided by a number of agencies including: Alberta/Canada Energy Resources Research Fund, Department of Energy, Mines and Resources Canada, Alberta Agriculture, the Farming For the Future Fund and TransAlta Utilities Corporation.

Mr. B. Paterson, Head of the Land Evaluation and Reclamation Branch of Alberta Agriculture (Lethbridge) is responsible for overall management of the Test Site. Mr. D. Baker, President of DRB Engineering Consultants Ltd. is responsible for data collection and analysis and computer systems operation and maintenance. Mr. E. Jensen, President of Jensen Engineering Ltd. is responsible for site design, liaison with wind turbine and solar manufacturers and data analysis related to economics and practical application of collected data. Temporary staff are hired as required to assist with day-to-day operation and maintenance of the site during summer operations.

Numerous publications have resulted from the testing carried out at the Lethbridge Wind Research Test Site since its formation in 1982 (Baker et al, 1987, 1986; Paterson et al, 1988, 1987, 1986, 1985). Demonstration days were regularly held to display the turbines and solar systems to the public and allow the manufacturers to discuss their machines. The response from these demonstration days and publications has helped to shape the direction and test methods presently found at the Test Site. In 1987, a well simulator was designed and constructed to allow for better evaluation of wind and solar systems at pumping depths up to 250 metres. This will provide needed information for manufacturers wishing to export their machines overseas.

This report describes the results of the testing carried out over the past three years at the Lethbridge Wind Research Test Site. In many cases, manufacturers carried out modifications to their machines during the testing period. The results presented in this report reflect the latest configuration of the machines located at the Test Site. The report is divided into four parts, a presentation of the ongoing low head pump tests, a discussion of the well simulator apparatus, a discussion on applications and marketing of water pumping windmills, and a summary of all sections of this report.

2.0 SITE DESCRIPTION

2.1 Site Layout

The test site is located one kilometre east of Lethbridge and is adjacent to an irrigation canal within the St. Mary River Irrigation District. The site was selected for the homogeneity of the surrounding terrain and the availability of water for the pumping circuits. Flat agricultural fields surround the test site causing a minimal amount of interference with wind flow. The site, because of its location beside the canal, was affected by a high water table and salinity problems due to canal seepage. A subsurface drainage system was therefore designed and installed in order to dewater the area plus provide a practical demonstration of actual field conditions in which the turbines would work.

Eight wind turbines and two photovoltaic water pumpers were tested in 1987. The location of these is shown in Figure 2.1. The solar energy incident on the photovoltaic panels was monitored at the location of the panels. Because of the homogeneity of the surrounding terrain, one tower was installed and considered sufficient for monitoring wind speed (Figure 2.1).

2.2 Description of Pumping Systems

Table 2.1 provides a list and brief description of the pumping systems tested in 1987. More detailed descriptions are presented with the performance results later in this report. Specifications and photographs of the systems may be found in Appendix A. The last two units shown in Table 2.1 are the photovoltaic pumping systems. Table 2.1 shows that the machines tested in 1987 represented a good cross-section of machines currently on the market.

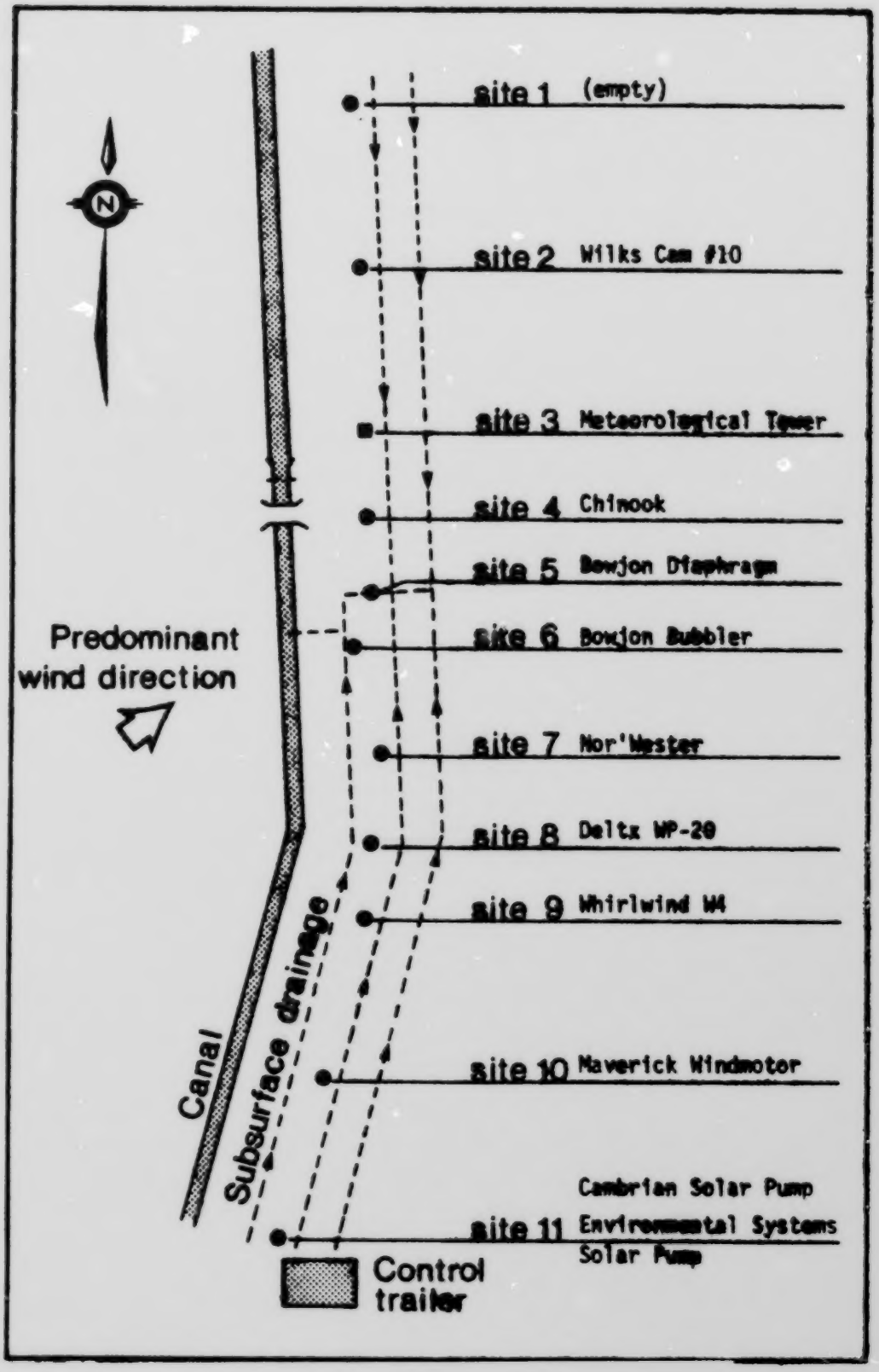

Figure 2.1 Site Layout

Table 2.1 - Pumping Systems Tested at the LWRTS

Model	Description	Supplier
Wilks Cam 10	Multi-blade rotor, piston pump driven with a cam/ roller system	Wind Energy Unlimited, Inc. Carson City, Nevada
Chinook 7.5	Multi-blade rotor, piston pump driven with a direct-drive crank	Canadian Agtechnology Partners Ltd. Olds, Alberta
Bowjon Rancher (2 Units)	Multi-blade rotors, air lift bubbler & diaphragm pumps	Prairie Ditching Ltd. Lethbridge, Alberta
Maestro	3-blade rotor, AC electric generator with battery storage driving a submersible pump	Nor'Wester Energy Systems Ltd. Calgary, Alberta
Deltx WP-20	8-delta blade rotor, dual piston pumps driven hydraulically	Deltx Windpump Corporation Calgary, Alberta
Whirlwind W4	2-blade rotor, 3-phase AC electric generator, centrifugal pump	Danecraft Mechanical Design Ltd. Calgary, Alberta
Maverick Windmotor	2-blade rotor, cable driven helical pump	Massey Enterprises Fort MacLeod, Alberta
Environmental Systems	Arco photovoltaic panels with centrifugal pump	Environmental Systems Canada Ltd. Ingersol, Ontario
Campro portable solar pumping system	Arco photovoltaic panels with multi-stage centrifugal pump	Cambrian Engineering Group Ltd. Saskatoon, Saskatchewan

2.3 Instrumentation and Monitoring Equipment

To measure the pumping performance of the systems, closed-loop double sump systems were installed. A schematic of a typical pumping circuit is shown in Figure 2.2. The unit being tested pumps water from one sump, up a predetermined height and then into a vented standpipe. The piping used in this portion of the test circuit is sized to be consistent with actual field applications while presenting negligible dynamic head to the pump. The vented standpipe is used to separate air from the pumped water and to dampen the pulsating flows before draining through a flow-metered pipe into the second sump. Each of the turbine-type flow meters are equipped with a flow rate register for local readout as well as a pickup for remote sensing. The metered pipe is designed to ensure valid flow readings. This required sloping of the pipe to guarantee continuous submergence of the flow meter and sizing the pipe to decrease the turbulence in the pumped water before measurement. The design also ensured that the dynamic head developed in this section would not raise the water level in the standpipe to a point where it would contribute to the pumping head of the wind turbine. The water exiting the metered pipe provides potential users with visual evidence of the wind turbine capabilities. The loop is completed when the pumped water returns to the first sump through a connecting pipe located near the base of the two sumps.

Atmospheric monitoring for the wind turbines was performed by the centrally located meteorological tower. A Climatronic weather monitoring package was installed on the 16 metre tower. The package consists of:

1. Four horizontal wind speed sensors mounted at 7.5, 10.0, 12.8 and 16.5 metres. The locations of the sensors were chosen such that the hub height of any wind turbine tested was within one metre of the height of a wind speed sensor.

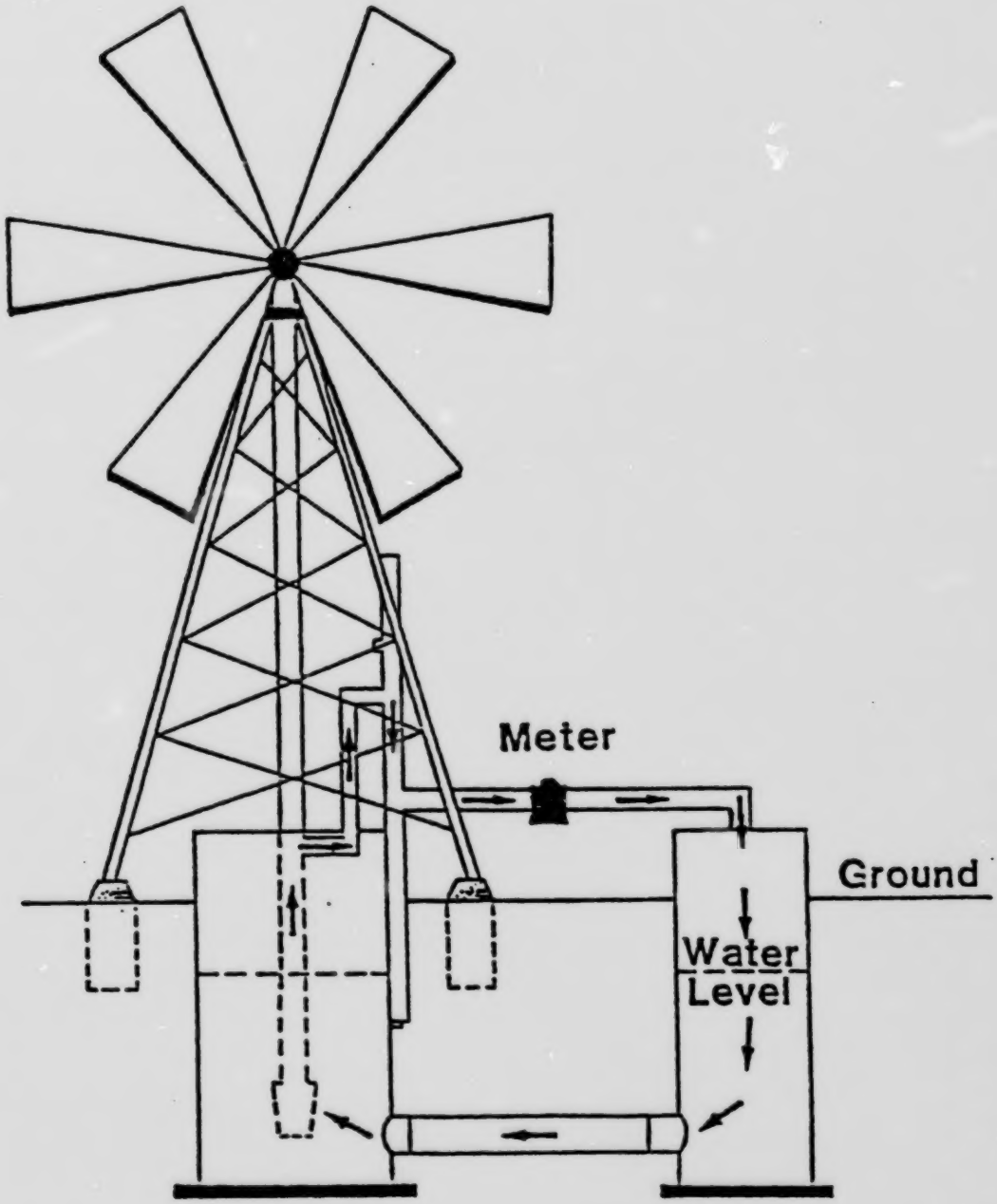

Figure 2.2 Typical Pumping Circuit

2. One wind direction sensor mounted at 10.0 metres. This sensor is used to determine the possible existence of 'wind shading' for the various wind turbines and anemometers.
3. One ambient temperature sensor mounted at 10.0 metres and one atmospheric pressure sensor mounted at 2.0 metres. These sensors are used to determine the atmospheric air density.
4. Local displays of the wind speed and direction at the 10.0 metre level for demonstration purposes.
5. Signal conditioners such that all sensor outputs can be transmitted to the data acquisition system in a consistent manner.

The effect of solar radiation on the performance of the solar pumping systems was monitored by a Kipp and Zonen pyranometer. The pyranometer monitored the solar radiation incident on the photovoltaic panels and was mounted at and on the same inclination as the panels.

There are many parameters which can be measured to evaluate the performance of solar and wind turbine pumping systems. It was decided that the performance variables of most interest to users and manufacturers were: the volume flow rate as a function of wind speed and solar energy; the variation of flow with pumping head and the predicted flow volumes in a given solar and wind regime. Manufacturers are also interested in the overall performance characteristics and efficiency of their machines in order to make improvements to the designs. In view of these priorities, along with budget and time constraints, it was decided to monitor pumping flow rates for each solar and wind pumping system. Infrared photo pickups were also installed on wind systems to monitor their rotor speed or pump cycle speed. The pickups were installed only on those machines which would not require the sensors to rotate. Future plans for additional monitoring include the addition of voltage and current sensors for the solar and electric wind turbine pumping systems.

The monitoring system on the site consists of a SAFE 8000 data acquisition unit and an IBM PC/XT. The SAFE 8000, programmed in an extended BASIC, samples all atmospheric sensors each second and

calculates the one and ten minute average and standard deviations of these values. In addition, the one second peak wind gust at the 12.8 metre level is also determined on the theory that turbine failure will more likely result from instantaneous high wind gusts than from sustained high average winds. The pulse inputs from the flow meters and photo pickups are totalled at the end of each one and ten minute interval coinciding with the atmospheric measurements. At the end of the ten minute interval, the minimum one minute value over the ten minutes is also determined. This value indicates whether the pumping system began or stopped pumping during that ten minute interval. The results of these calculations are then transmitted to the IBM PC/XT. Both systems are housed in an environmentally controlled trailer located at the south end of the test site. The flow of data through the SAFE 8000 and the IBM PC/XT is illustrated in Figure 2.3.

The IBM uses a UNIX based operating system such that it can operate in a multiuser/multitasking environment. A series of scheduled programs, written in C language, is used to facilitate the data collection, processing and transmission. The on-site processing includes producing hourly averages of each sensor input and automatically producing daily summary reports of these values. The ten minute average data is stored on the hard disk (providing thirty days of backup storage), and once per day is transmitted via DATAPAC telephone linkage to the University of Alberta mainframe computer. A menu system is provided to on-site and remote users (connected via modem) enabling them to perform a variety of functions. These include manually initiating the previously discussed automated procedures for any data interval. The user may also obtain in a similar fashion data from any of the machines being tested for direct use with a spreadsheet/graphics package such as Lotus 1-2-3. Finally, the menu system allows the user to monitor in real time the operation of the site using the one minute data. The operating system is also configured such that password protection prevents unauthorized personnel from modifying the IBM or SAFE software. Because of the UNIX based operating system, all of these tasks can be performed

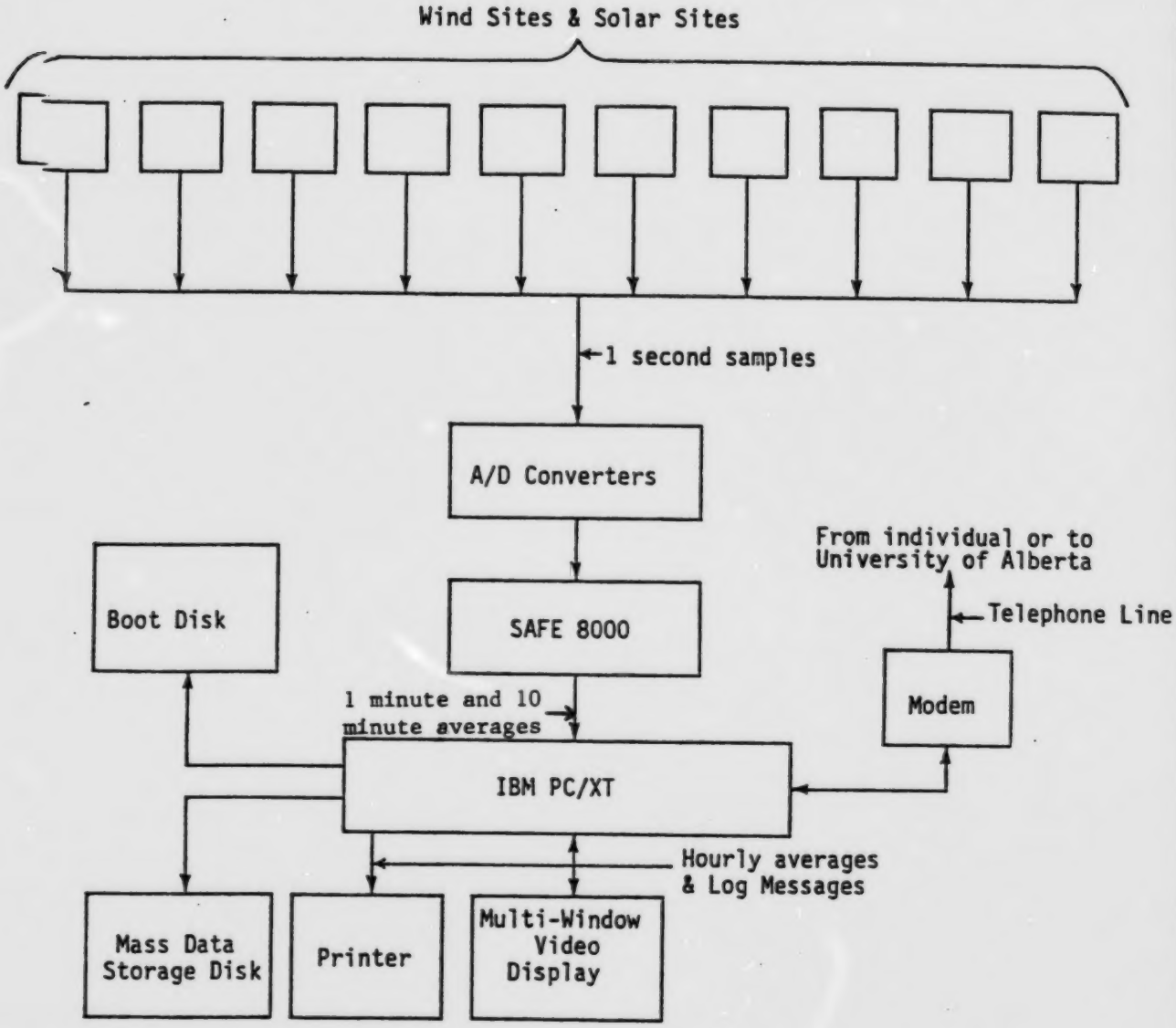

Figure 2.3 Data Acquisition System

without interrupting the data monitoring process.

Additional improvements were made to the monitoring system during 1987. The user interface was upgraded to a LOTUS menu system. Also, the data transmission software was expanded to allow the transmission of data to multiple destinations. Implementation of this system in 1988 will result in the data being archived and analyzed with an IBM workstation at DRB Engineering Consultants Ltd. This will increase the speed and flexibility of data analysis and allow ongoing evaluation of the machines during the test season.

3.0 ANALYSIS PROCEDURES

The following section describes the methods used to calculate the performance characteristics of the wind turbines tested. Since the reliability of the wind turbines is very important, the test site maintained logs of each machine which included their installation date and down times due to machine repair. These logs were used to calculate the number of weeks the machines were tested and the fraction of time during this test period the machines were available for operation (regardless of wind conditions). This data will be discussed after presentation of the performance curves.

3.1 Performance Curves

The monitoring and analysis procedures at the test site closely followed the Canadian Standards Association (CSA) Preliminary Standard F417-M1987 "Wind Energy Conversion Systems (WECS)-Performance", with the proposed amendments presented by R.G.Richards and accepted by the CSA subcommittee members on June 18, 1986. The monitoring method of sampling once per second and averaging over a ten minute interval agrees with the CSA standard. The only exception to the monitoring standard was that the test site did not install a separate anemometer for each wind turbine being tested. Not only would this have been an

extremely costly modification, but because of the smooth terrain characteristics of the site it was deemed unnecessary. The collected data was first divided into separate files for each machine. These files were then filtered for invalid data sets caused by machine or monitoring failures. The files were then filtered again for data sets in which the anemometers or the machine could have been shaded by surrounding turbines. In the case of the Maverick Windmotor, the data was also filtered for periods when the wind may have been shaded by a section of trees located across the canal and south of the test site. As many of the machines were installed or modified late in the test season, an attempt was made to incorporate as much data as possible. The most significant method of reducing the amount of eliminated data was to decrease the wind direction angle through which wind shading was deemed possible. To determine what angle was "safe", data was collected on the standard deviation of wind direction over each ten minute interval. The results showed that the median standard deviation was 15 degrees, which meant there was a 5% chance that the wind direction would deviate more than 30 degrees from the mean (2 standard deviations) for a period of one second in the ten minute interval (assuming a normal distribution). The chances would quickly approach zero as the time interval for wind directions outside the 30 degree range was increased. Hence, any data in which the mean wind direction was within 30 degrees of an obstruction was eliminated. This differs from the CSA preliminary standard which requires the mean wind direction to be 45 degrees away from an obstruction. Further validation of this reduced angle will be performed in the 1988 test season when actual minimum and maximum wind directions will be recorded for each ten minute interval.

After the above two filtering methods were applied to the data files, the data sets were divided into wind speed bins. For wind speeds less than 8 m/s, the width of each wind speed bin was 0.5 m/s; for winds greater than 8 m/s, the bin width was 1.0 m/s. This increased interval still agrees with the CSA standard and was applied due to the decreased amount of data recorded above 8 m/s. The mean

and standard deviation of each recorded parameter was then calculated for each wind speed bin. The results were then used for the final filtering process. Chauvenet's criterion (Holman, 1978), also recommended for incorporation into the CSA standard (CSA Technical Committee on Wind Energy Conversion Systems, June 19, 1986), allows the elimination of spurious data with unknown origins which is greater than approximately two standard deviations away from the mean within each wind speed bin. This criterion was applied to the measured flow rates and, if monitored, the rotor speeds. The averages and standard deviations for all parameters in each wind speed bin were then recalculated.

A final test specified by the CSA standard to determine the statistical validity of the data was applied before graphing the results. This final test checks to see if the data meets specified minimum data base requirements (MDBR) and is defined as follows:

1. For wind speed bins in which the parameter to be graphed (flow rate or rotor speed) is less than 25% of the maximum or rated value, then the bin shall not meet the MDBR until at least forty 10 minute averages of power are obtained. This controls the data such that the true mean of the bin is contained within a confidence interval of 1 standard deviation of the sample mean with a probability of 0.99.
2. For wind speed bins less than 15 m/s, the bin does not satisfy the MDBR until; (a) there is at least ten samples in the bin, (b) there is a probability of 0.99 that the true mean of the bin is within 10% of the sample mean. The method for determining this value is presented in detail in the CSA standard.
3. For wind speed bins greater than 15 m/s, the bin does not satisfy the MDBR until; (a) there is at least ten samples in the bin, (b) there is a probability of 0.99 that the true mean of the bin is within 10% of the sample mean. This calculation is a slight variation of the above.

The results of the MDBR test, along with the average and standard deviations of each parameter within each bin are tabulated in Appendix B. The flow rate and rotor speed values are then plotted against wind speed. Finally, a smooth curve drawn through these plotted points represents the performance curve. The data points taken off the smooth curve are then recorded and used in subsequent analyses.

3.2 System and Pump Efficiency Curves

Using the data points from the performance curves it is possible to determine the efficiency of the system. The system efficiency (Cp) is defined as the fraction of power available to the wind turbine which is converted to usable energy in the form of pumped water:

$Cp = QHW/(0.5dAv^3)$;

where Cp = wind turbine system efficiency

Q = measured flow rate (l/s)

H = pumping head (m)

W = Specific Weight of water (9.805 kN/m^3)

d = measured air density (Kg/m^3)

A = area perpendicular to the rotor axis that the rotor covers during one complete revolution (m^2)

v = measured wind speed (m/s)

In the case of the solar pumpers, the system efficiency is based on the available energy from the sun which strikes the panels. The equation is thus changed to:

$Cp = QHW/(RA)$;

where Cp = solar pumper system efficiency

Q = measured flow rate (l/s)

H = pumping head (m)

W = Specific Weight of water (9.805 kN/m^3)

R = solar radiation incident on the photovoltaic panels (W/m^2)

A = area of the photovoltaic panels (m^2)

The volumetric efficiency (Ve) of the pump can be calculated for systems incorporating piston pumps whose pump cycle speed was measured. It is defined as the fraction of water which could theoretically be produced by the pump which is actually observed to be pumped:

$Ve = Q/(PV)$;

where Q = measured flow rate (l/s)

P = pump cycle speed (cycles/s)

V = theoretical pump volume per cycle (volume/cycle)

3.3 Monthly Pumping Estimates

The final calculation made from the performance curves is the potential monthly pumping estimates. These estimates are based on the pumping system being available for operation whenever the wind speed exceeds the cut-in speed of the system. They are also based on wind regimes which display Rayleigh characteristics. That is the frequency of time winds are found within any wind speed interval (e.g. from v_x to v_y) may be calculated by incorporating the mean wind speed ($\bar{v}$) in the following equation:

$$F(v_x \leq v \leq v_y) = \exp[-(\pi/4)(v_x/\bar{v})^2] - \exp[-(\pi/4)(v_y/\bar{v})^2].$$

To calculate the wind turbine's monthly pumping potential, the flow rate values measured from the final performance curve within each wind speed bin are multiplied by the fraction of time (F) that the wind would blow within that wind speed interval. The sum of these values is equal to the average pumping rate of the wind turbine. The potential volume the system could pump is then determined by multiplying this average with the time period in question (this study uses 30 day months). Repeating this calculation for a variety of mean wind speeds allows the graphing of the monthly pumping potential against mean wind speed.

4.0 PRESENTATION AND DISCUSSION OF RESULTS

The following section presents and discusses the performance characteristics of the wind turbines tested. The "bin" data used to generate the graphs has been tabulated in Appendix B which also includes scatter plots of the raw data used to determine the bin data. These tables also indicate the average turbulence intensity and air density observed in each wind speed bin.

The turbulence intensity is a measure of the variability of the wind speed over each ten minute period and is expressed as the ratio of the first standard deviation of wind speed the the mean wind speed. An analysis for the entire period showed that the turbulence intensity for winds at ten metres elevation average fourteen percent. This is a relatively low value which provides another indication that the data collected by the meteorological tower accurately represents the winds experienced by the entire site.

The average air density recorded during the test season was 1.1 kg/m^3. In accordance with the CSA performance testing standard, the performance data have not been adjusted to standard atmospheric conditions.

4.1 Performance Curves

Figures 4.1 to 4.13 present the pumping performance of the systems tested in 1987. The graphs indicate the mean and standard deviations recorded in each wind speed bin. The solid line represents the smooth fit curve. Some graphs also include a dashed line, which represents an extrapolation of the machine's performance and is not statistically valid (i.e. does not meet the MDBR specification in the CSA standard) but allows the estimation of monthly pumping potentials.

4.1.1 Wilks Cam 10

This unit was installed in the latter part of the 1986 test season and a partial performance curve was produced in the LWRTS

1986/87 Summary Report (Paterson et al, 1987). The system was then modified prior to the 1987 test season, thus Figures 4.1 and 4.2 show only the performance of the unit's 1987 configuration. The turbine rotor is 3 metres in diameter and consists of 28 blades. It is very similar to the standard American water pumper in appearance. However, its cam drive system reduces the wind speed required for cut-in. The system works by rotating a cam which is machined such that three-quarters of the cam is used for the lifting stroke and the other quarter is used for the return stroke. The cam is driven by a gear mechanism which requires 3.77 turns of the rotor for each cycle of the cam. Since the pump rod rides this cam, the maximum torque required for lifting is reduced. The rotor performance is shown to be quite consistent by the smoothness of the curve and the relatively short standard deviation bars. The performance curve revealed unusual behavior in the piston pump used with the Wilks machine. For winds above 5 m/s, it pumped a lower volume than would be expected for the corresponding rotor speed, and above 8 m/s the pump operated sporadically (Figure 4.1). During the winter months it was discovered that the problem was caused by the center valve in the piston pump not closing properly on the down stroke. Because of the relatively low cut-in wind speed on this unit, it is expected to have good potential once this pump problem is solved.

4.1.2 Chinook 7.5

The Chinook windmill also has a multi-bladed rotor. The rotor is 7.5 metres in diameter, consists of 24 blades, and drives a piston pump by means of a direct drive crank. Thus, each rotation of the rotor produced one cycle of the pump. The drive crank was set to provide the 305 mm diameter piston pump with a 305 mm stroke. The unit has been on the site since the winter of 1985 and the performance of its prior configurations can be found in the LWRTS 1986/87 summary report (Paterson et al, 1987). The performance of this unit in its final configuration tested is shown in Figures 4.3 and 4.4. The cut-

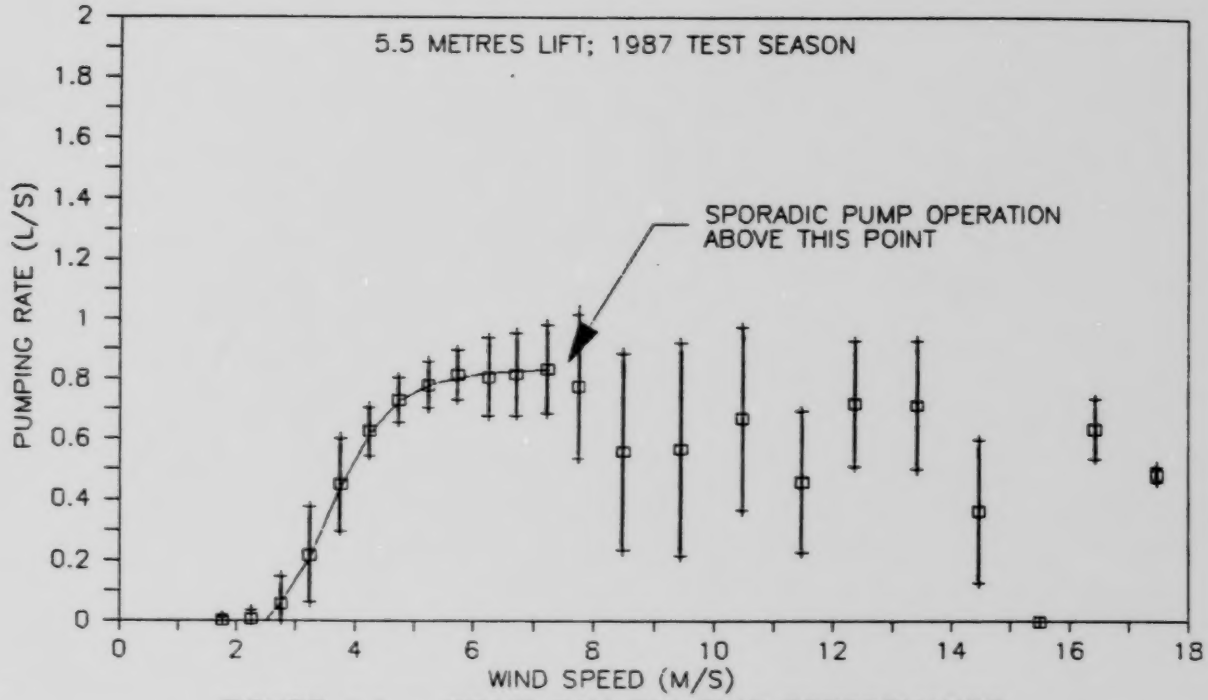

FIGURE 4.1 – WILKS CAM PUMPING PERFORMANCE

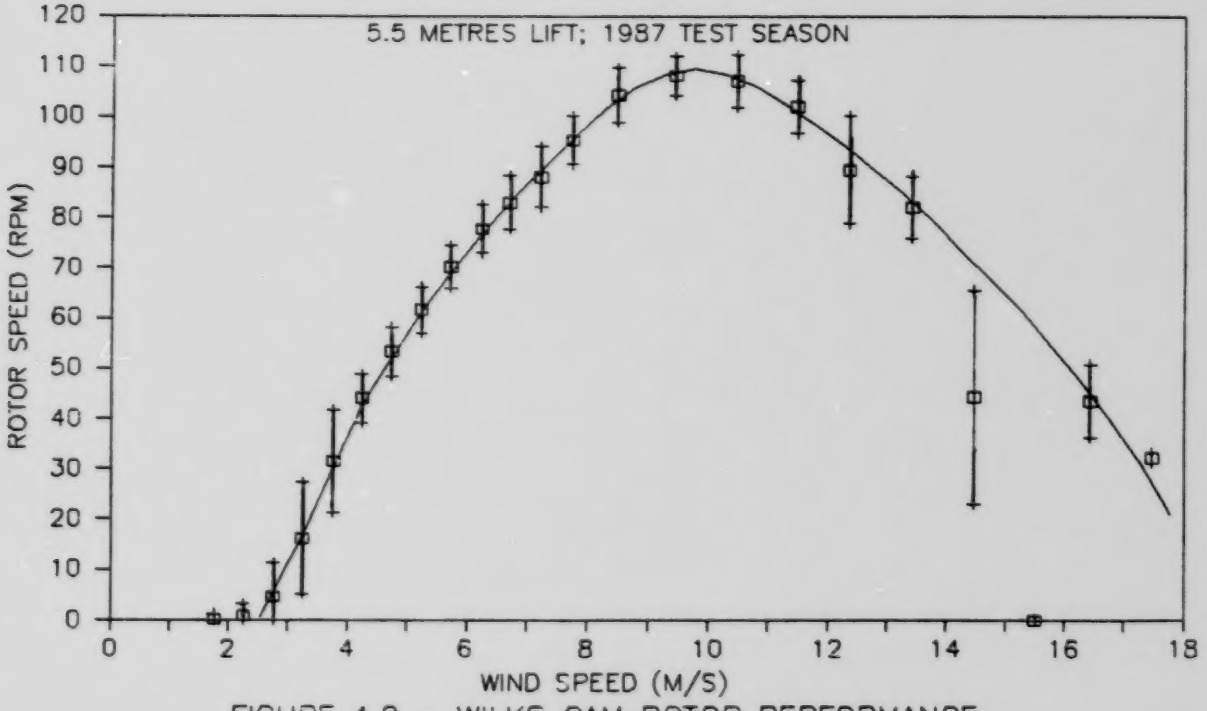

FIGURE 4.2 – WILKS CAM ROTOR PERFORMANCE

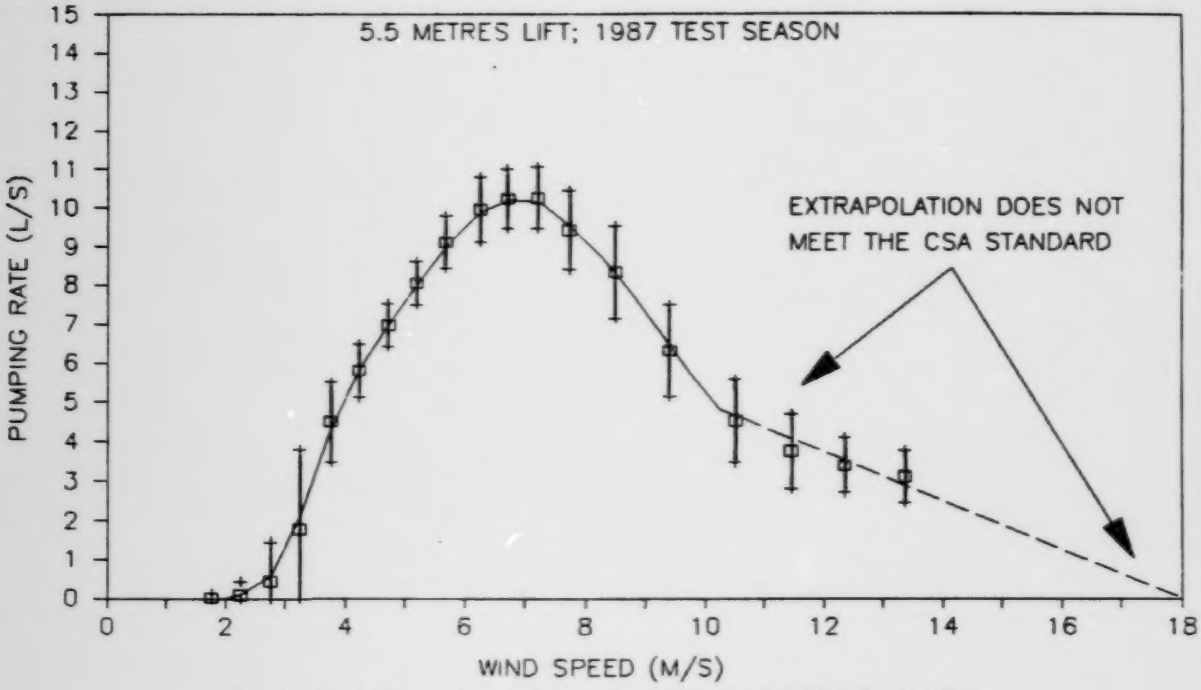

FIGURE 4.3 – CHINOOK PUMPING PERFORMANCE

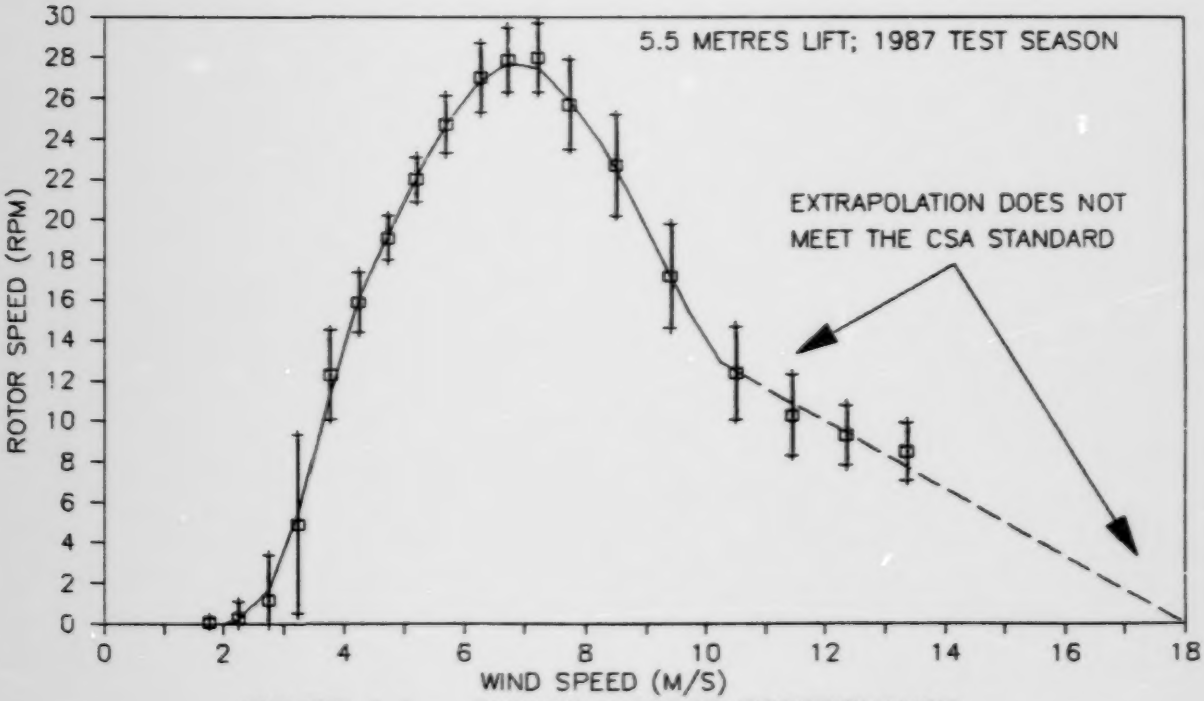

FIGURE 4.4 – CHINOOK ROTOR PERFORMANCE

in wind speed of 2 m/s is the lowest of the mills tested in 1987. It also initiates furling at the lowest wind speed of the mills tested. Although the data above 11 m/s does not meet the minimum database requirements of the CSA standard, the performance curve was extrapolated on the basis of previous testing on this machine and the small amount of data collected at the higher wind speeds. By performing this extrapolation it will be possible to estimate the Chinook's monthly pumping potential.

4.1.3 Bowjons

The performance of the two Bowjon units is shown in Figures 4.5 and 4.6. These units were repeatedly modified throughout the test season, but only the performance results of their final configuration is shown. The Bowjon Diaphragm's final configuration consisted of six polystyrene blades providing a rotor diameter of 2.4 m and a Warren-Rupp air-operated diaphragm pump. This configuration allows the system to begin pumping sooner then the previously tested Bowjon Diaphragm (2.0 m/s versus 2.5 m/s), but its peak output is only 43 percent of the previously measured peak (1986 test season; Paterson et al, 1987). To provide an estimate of its monthly potential pumping volume, the performance curve from this unit has been extrapolated on the basis of previous tests.

The Bowjon Air Lift unit tested incorporated the company's revised rotor. The rotor consisted of 5 tear-drop shaped blades which provide a rotor diameter of 1.8 m. This rotor diameter results in a swept area which is 44 percent smaller than that of the previously tested Bowjon Air Lift units. Only a small amount of data was collected on this configuration, but preliminary results suggest that it has a higher cut-in wind speed (3.0 m/s) and lower peak production compared to the previously tested Bowjons. It is estimated that the peak will be near 0.2 l/s, which is only 20 percent of the original Bowjon's peak (1984 test season; Paterson et al, 1985) and 38 percent of the first revised configuration's peak (1986 test season; Paterson

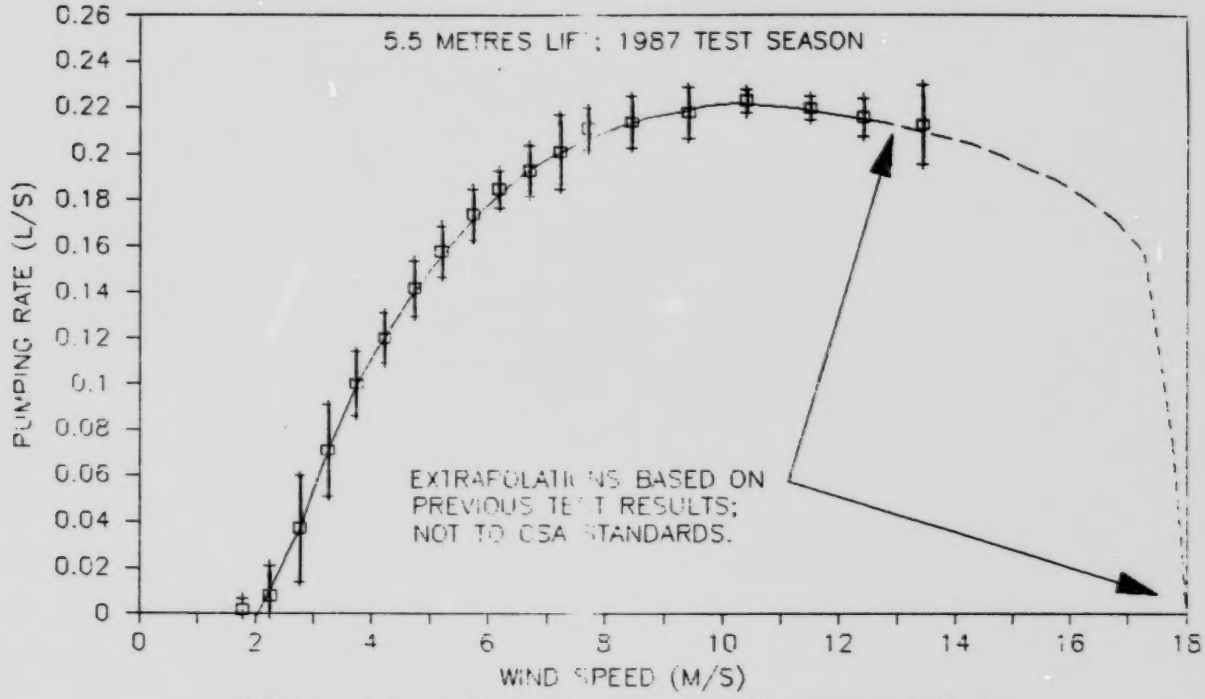

FIGURE 4.5 – BOWJON DIAPHRAGM PERFORMANCE

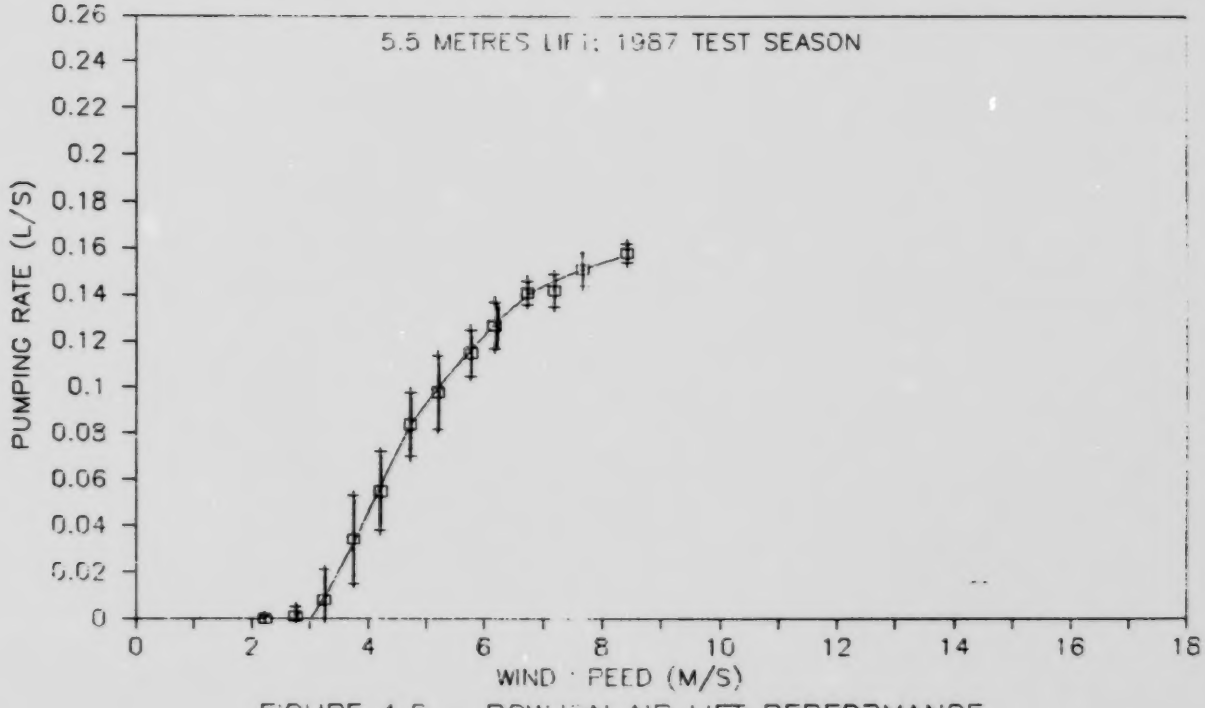

FIGURE 4.6 – BOWJON AIR LIFT PERFORMANCE

et al, 1987). Since this decrease in performance is greater than 44 percent, it cannot be entirely attributed to the decrease in swept area.

4.1.4 Deltx WP-20

The Deltx WP-20 wind turbine's performance is shown in Figures 4.7 and 4.8. This delta-bladed wind turbine was the subject of a separate study performed in the spring of 1986 (Baker, 1987). The study indicated that the stress caused by a complex mechanical linkage system, which was used to drive the dual piston pumps, resulted in continual breakdowns. Since then the manufacturer has replaced the mechanical linkage with a hydraulic drive mechanism. The system consists of four reciprocating pistons located behind the rotor in a circle around an off-set crank which is directly linked into a dual acting cylinder near the base of the tower. The cylinder then drives the pumps in a reciprocating fashion. The pump cycle is accomplished by a switching device which reverses the hydraulic flow in the cylinder each time the pumps reach the end of their stroke. This configuration is much simpler and has the potential to be quite reliable. Unfortunately, during testing a flaw in the switching device periodically directed flow to both ends of the driving cylinder. This stopped any pumping until the switch was manually reset. As a result the performance data presented was collected over a series of tests when the unit was operational. Also, because the WP-20 came with its own test bed, the pumping head was fixed at 5.0 metres (versus 5.5 metres for the rest of the test units). The unit's peak production shown in the figure is 10 percent lower than that achieved by the previous configuration, however, its cut-in wind speed has been decreased from 4.0 m/s to 3.5 m/s. The performance of this machine has also been extrapolated to facilitate the estimating of the WP-20's monthly pumping potential (assuming the switching device problem could be overcome).

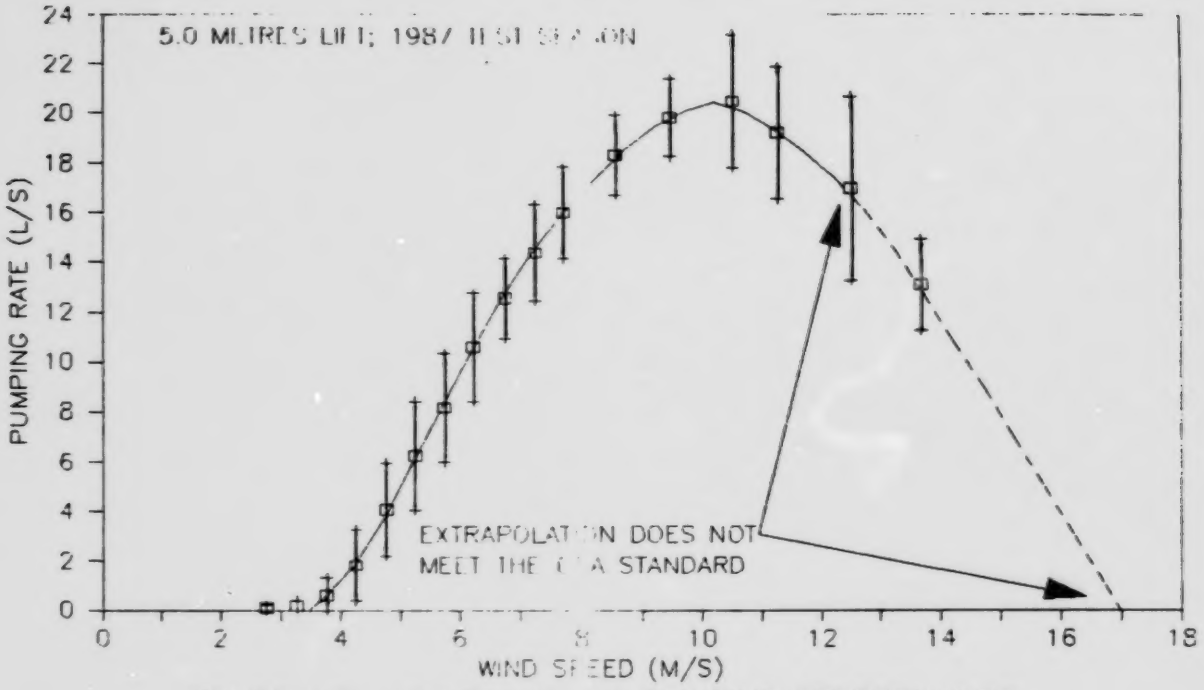

FIGURE 4.7 – DELTX WF-20 PUMPING PERFORMANCE

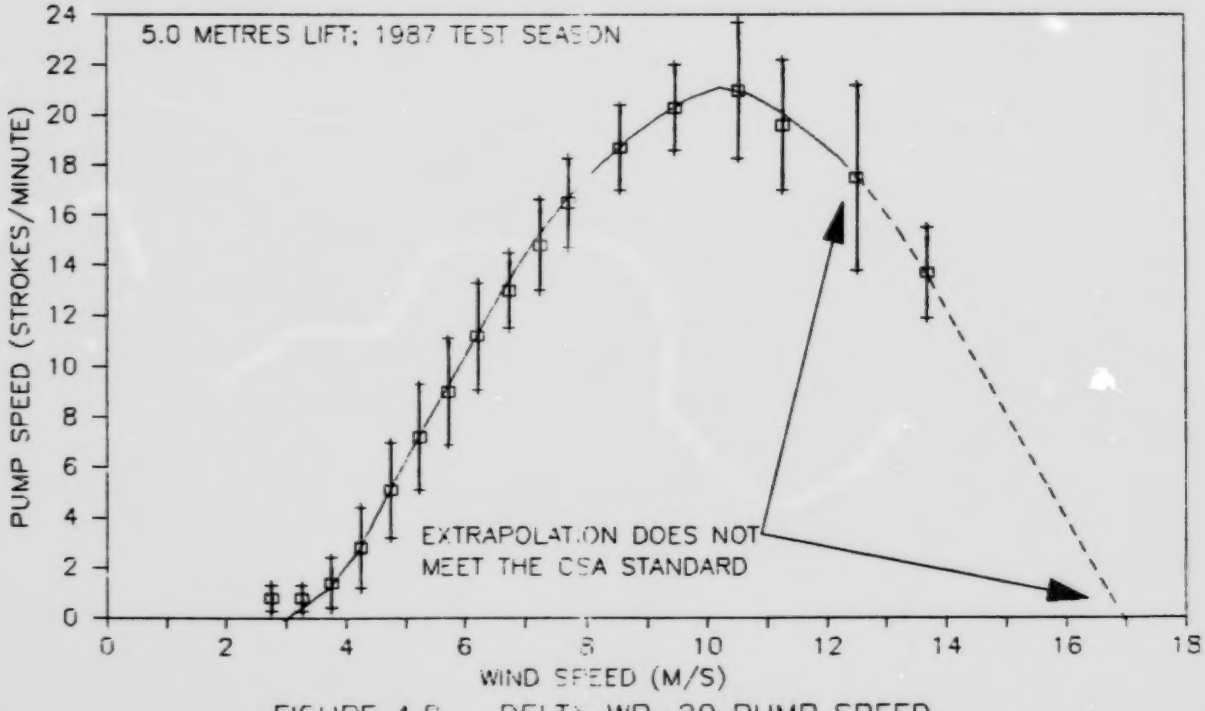

FIGURE 4.8 - DELTX WP-20 PUMP SPEED

4.1.5 Maestro

Figure 4.9 shows the performance of the Maestro wind turbine pumping system. This is the first electric wind pumping system to be installed on the site which incorporates a battery storage system. The objective in using batteries was to provide more continuous pumping availability, and thus decrease the amount of storage required when using this turbine. This was to be achieved by storing excess energy during periods of high winds (which is lost with typical water pumpers because of their low wind speed furling characteristic) and using it during periods of low winds. Hence, the system was designed such that in high winds sufficient energy would be delivered to the pump to drive it at its design flow rate of 1.6 l/s and the remaining energy would be diverted to battery storage. During periods of marginal winds, the batteries would assist the turbine in supplying energy to the pump to achieve its design flow rate. Finally, when the turbine was not operating, any reserve power in the batteries would be used to maintain the flow from the pump. It was hoped that fully charged batteries could sustain the design flow rate for up to five hours after the cut-out of the wind turbine. This would then effectively provide energy for pumping water during low winds, yet still take advantage of the greater efficiency of electric turbines in high winds.

The design tested used a 1 kW, single phase, variable frequency, 24 VAC Bergey wind turbine. The power was rectified to DC and stored in 220 Ah, 24 V batteries. The power from the batteries was then inverted to 60 Hz, 110 VAC to power a submersible pump rated at 250 W. If the system ran as designed, the plot of flow rate versus wind speed would be expected to consist of one line at its design flow rate, and another at zero flow. Figure 4.9 indicates that this was not the case; rather the performance curve had the characteristics of an electric pumping system without battery storage. It is believed this was due to greater power draws than expected by the pump motor, and a control system which did not allow sufficient energy reserves to be

maintained in the batteries. The size of the standard deviation bars is the result of the batteries acting as a short term buffer, and at times providing sufficient energy to allow the pump to operate near its design point during relatively low winds. This can be seen in more detail in the scatter graphs of the raw data contained in Appendix B. Had the data been restricted to periods when the system was operating continuously, the effect of battery cycling would be eliminated, causing the scatter to be reduced. From this curve, it can be estimated that the wind turbine begins providing useful power at 4.5 m/s, and supplies sufficient energy to drive the pump near its design point at 10.5 m/s. The manufacturer is aware of these battery/control problems and expects to make changes during the 1988 test season to achieve the objectives of his design.

4.1.6 Whirlwind W4

The Whirlwind is also an electric pumping system, but does not incorporate any battery storage. The system consists of a two-bladed rotor driving a three phase AC generator rated at 4 kW. The generator supplies power to a 200 V, three phase AC motor rated at 2.24 kW at 3500 RPM. This motor is then directly connected to a centrifugal pump. A logic control unit is used to avoid over-speeding of the wind turbine and limit the power supplied to the motor.

Figure 4.10 indicates that the unit has a very small operating range. It begins pumping at 4 m/s and the control system begins shutting down the turbine in winds above 11 m/s. After shutdown, the unit will be allowed to restart in winds below 14 m/s until the power output requires another shutdown. This causes the large standard deviations above 9 m/s, which in turn make it impossible to meet the minimum database requirements of the CSA performance testing standard. Even so, the curve drawn above 9 m/s is believed to accurately represent the performance of this machine.

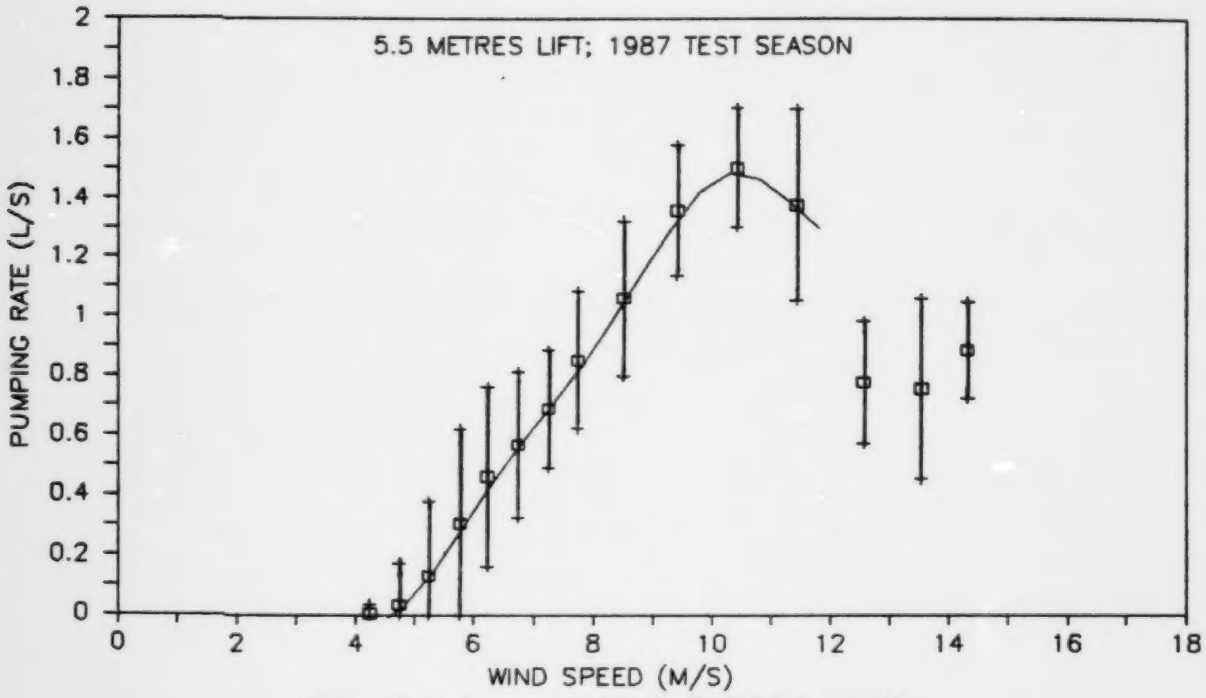

FIGURE 4.9 – MAESTRO PERFORMANCE

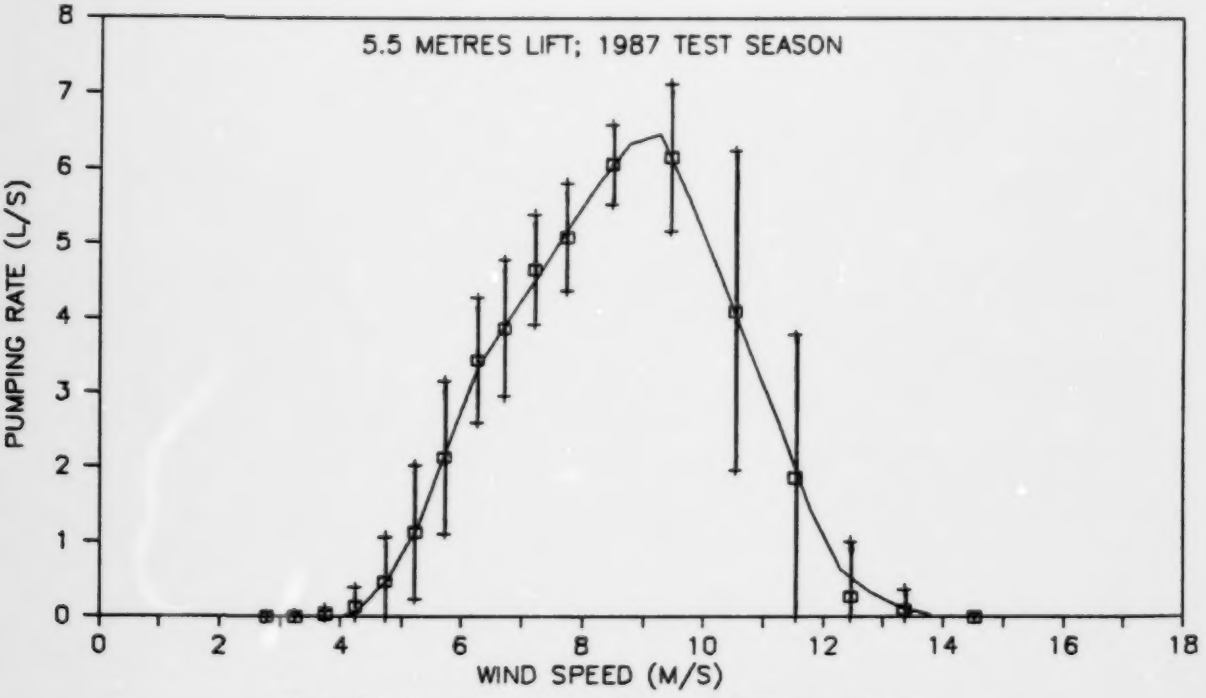

FIGURE 4.10 – WHIRLWIND PERFORMANCE

4.1.7 Windmotor

The Windmotor is a downwind, three-bladed machine with a rotor diameter of 2.4 m. The rotor is unique because the blades do not radiate out from the central hub, but are mounted perpendicular to the rotor supports at the extreme edge of the rotor circumference. The force of the wind on the blades combined with the rotational speed of the rotor regulates the pitch of the blades. This results in the unit being self regulating and removes the requirement for a cut-out wind speed. The water is pumped with a helical progressive cavity pump which is driven directly by the rotor via a flexible cable. The pump is designed to produce 13.6 litres per 100 RPM of the rotor.

The performance of this unit is shown in figures 4.11 and 4.22. As can be seen from the graphs, data was not collected in winds above 13 m/s. This was mostly caused by the fact that most high speed winds were eliminated from the data set because of potential shading from up-wind trees. The graphs do indicate that the rotor requires a speed of 40 RPM before the pump begins delivering water. This results in a relatively high cut-in of 3.5 m/s. The graphs also seem to indicate that the system is close to its maximum output at 13 m/s. Its exact potential is expected to be determined during the 1988 test season.

4.1.8 Solar Pumpers

Two photovoltaic water pumpers were tested during the 1987 test season and their performance is shown in Figure 4.13. The curves shown represent a smooth fit through the raw data points. No standard deviation bars are indicated on the graph because the data was not analyzed in the same detail as the wind pumping systems were. The graph indicates the difference in design of the two systems. The Environmental Systems unit is designed to have a low radiation intensity level cut-in, and achieve a moderate flow under clear sky conditions. The unit generates DC power from four Arco photovoltaic panels having a total area of 1.49 m^2 and a combined power rating of

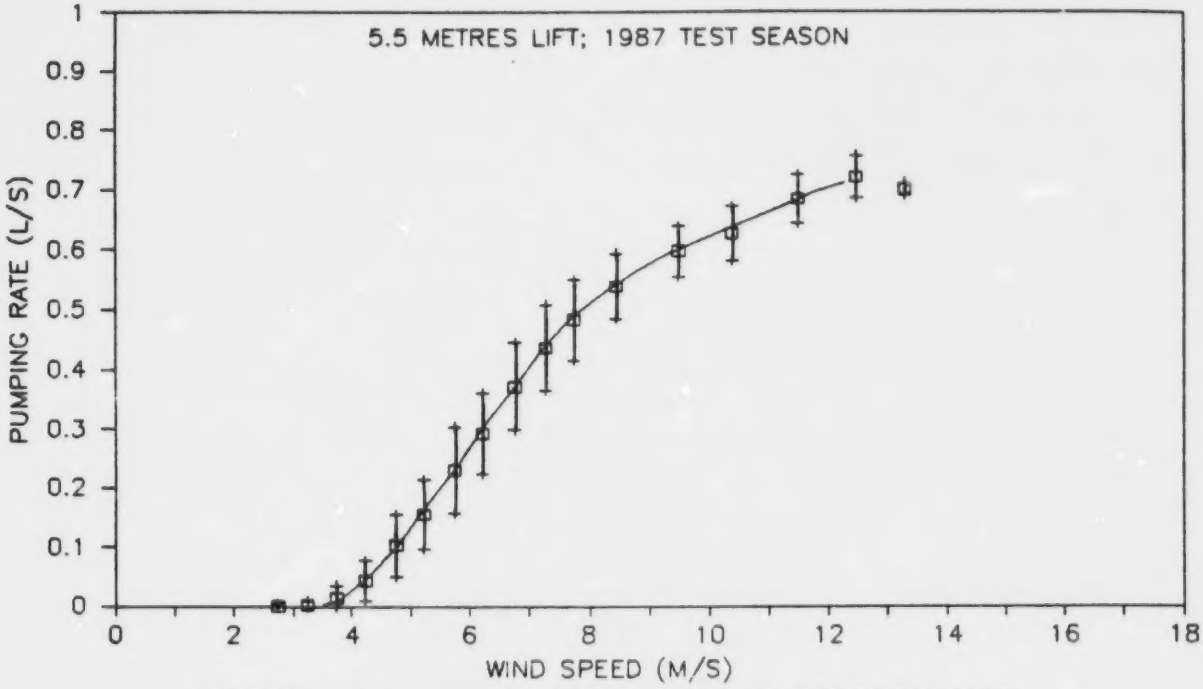

FIGURE 4.11 – WINDMOTOR PUMPING PERFORMANCE

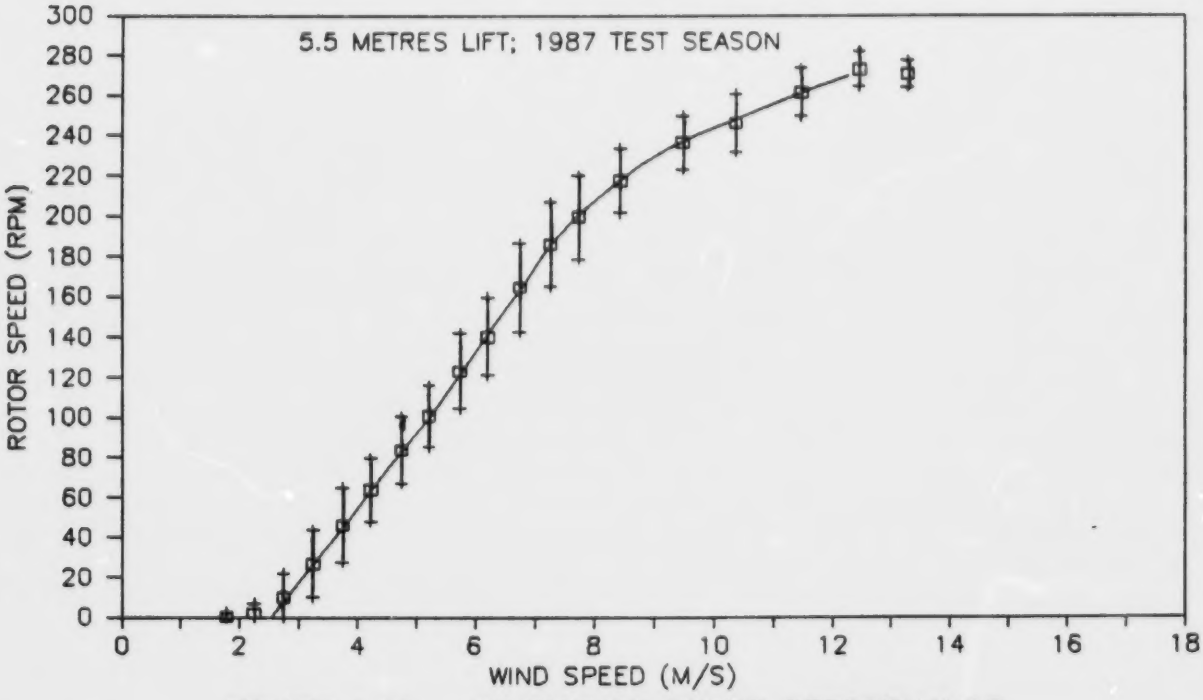

FIGURE 4.12 – WINDMOTOR ROTOR PERFORMANCE

172 Watts. The power is used to drive a single stage centrifugal pump. The low cut-in solar radiation intensity indicates that this unit would be ideal for areas which suffer from overcast conditions.

The Campro Portable system operates on the same concept as the Environmental Systems' unit. It consists of six Arco panels having a total area of 2.23 m^2 and a combined power rating of 250 Watts. The power from these panels is used to drive a multi-stage centrifugal pump. The performance curve of this configuration shows that a much higher level of solar radiation is required before it begins pumping. At its peak, it is able to pump 1.5 times the rate that the Environment Systems does. This corresponds to the difference in panel areas of the two systems. Because of its requirement for relatively high levels of solar radiation to initiate pumping, this unit would be most suitable for locations with predominantly clear sky conditions.

4.2 Mechanical Integrity

As mentioned previously, the test site maintained logs of each machine, which included their installation date and down times due to machine repair or modification. The results of these logs have been tabulated in Table 4.1. The table shows the testing period and what fraction of that time the machine was not being repaired or modified. These periods do not include the time during installation taken to make the system operational.

4.2.1 Wilks Cam 10

The Wilks Cam unit was operational for all but two weeks of the test season, resulting in an availability of 92 percent. One week was required to repair the system when the sucker rod became disconnected; another week was required when the oiler in the gear box quit working. During some of the operating time the pump was not performing as well as possible (in winds above 5 m/s). However, once this pump problem

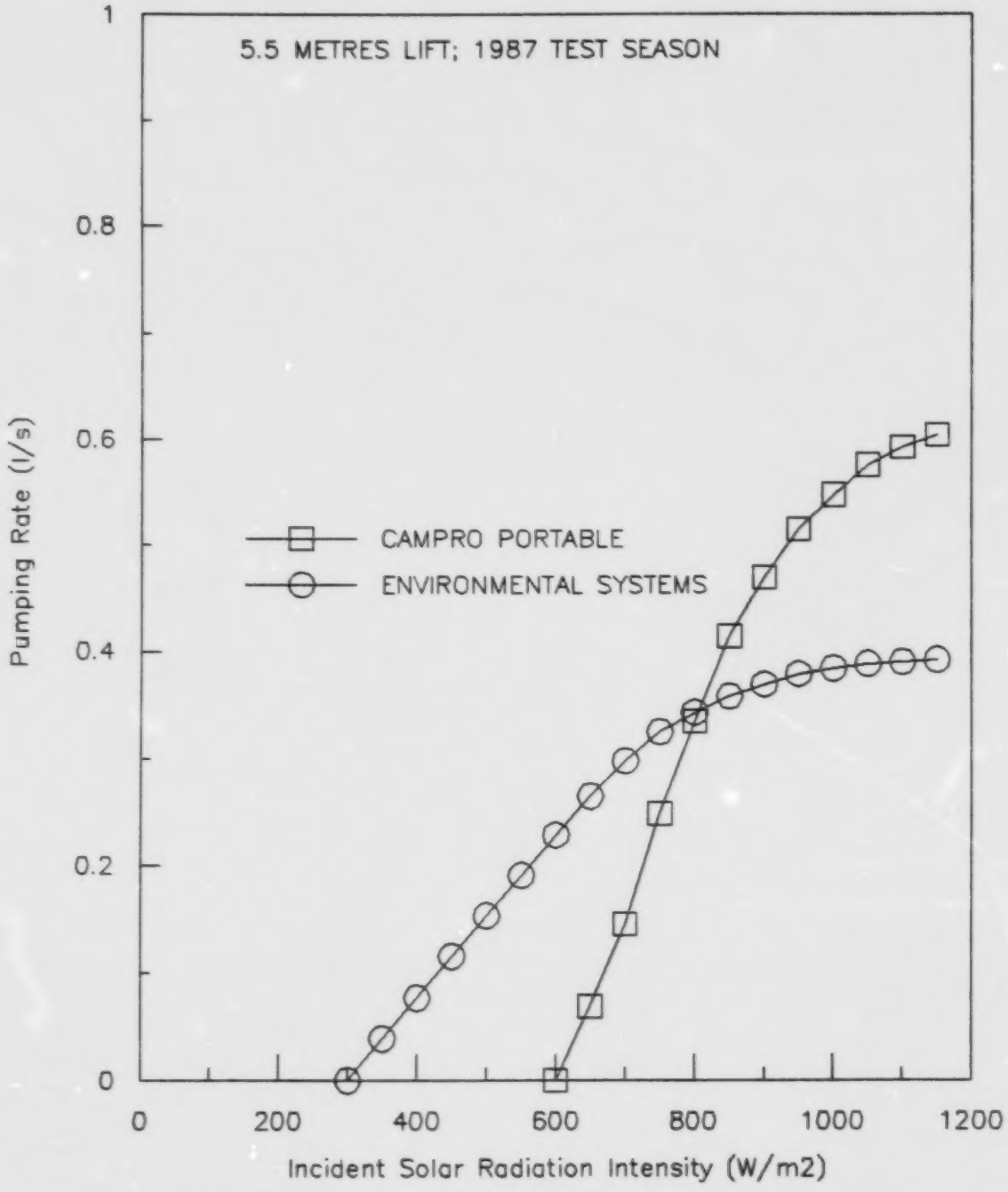

FIGURE 4.13 – PERFORMANCE OF SOLAR PUMPERS

Table 4.1 - Record of Availability of Tested Water Pumping Systems

Machine	Testing Period (Weeks)	Period Machine Available (Weeks)	(%-age of Time)
Wilks Cam 10	22	20	92
Chinook 7.5	22	12	55
Bowjon Diaphragm	21	15	71
Bowjon Air Lift	16	15	94
Deltx WP-20	21	5	24
Maestro	7	7	100
Whirlwind W4	13	13	100
Windmotor	17	15	88
Environmental Systems	22	19	86
Campro Portable	22	22	100

is repaired, this machine has good potential for achieving high levels of reliability.

4.2.2 Chinook 7.5

The Chinook unit was present during the entire 22 week test season, but almost half of this time was spent with the unit under repairs. There were three sources of these problems:

1) The shear pin connecting the sump rod to the pump sheared a number of times due to the cyclic loading on the pin. The windpump system was not designed for high volume, low head applications which require a downward force to drive the pump to the bottom of its stroke.
2) The threaded connection between the rotor head and the pump repeatedly came unscrewed because of an inadequate swivel design for the loads experienced in this application.
3) The ringfeder (the mechanism which attaches the crank to the rotor shaft) damaged the rotor shaft when it failed due to improper installation. The entire rotor assembly was subsequently removed to replace the damaged shaft.

These problems were corrected by mid-August, and the unit ran without further repairs for the rest of the test season. Further testing is required before the reliability of these repairs can be determined.

4.2.3 Bowjon Diaphragm

This unit was in place for most of the 1987 test season, and was available for operation 71 percent of the time. Six weeks were spent repairing the unit; three to install custom made transparent polystyrene blades, and three more to install thicker blades after the first set failed. It is believed the use of polystyrene blades is unique for this application, therefore its reliability cannot be determined until further testing is completed.

4.2.4 Bowjon Air Lift

Although Table 4.1 indicates that this unit was tested for 16 weeks, its final configuration was only tested for three weeks. As with the Bowjon Diaphragm system, this unit will require further testing before its reliability can be assessed.

4.2.6 Deltx WP-20

As shown in Table 4.1, this unit had the lowest level of reliability of the machines tested during 1987. The source of this problem was discussed during the presentation of its performance curve, section 4.1.4. As a result of the pump drive problem, the unit never ran continuously for more than two weeks. If this problem is solved, the use of the hydraulic drive system to eliminate pump linkages may allow the system to achieve high levels of reliability. Presently, it is not known whether the manufacturer will attempt to solve this problem during the 1988 test season.

4.2.7 Maestro

This is a prototype system with ongoing changes in the control and pump configuration. The first workable configuration was installed in the third week in August. For the remainder of the test season the unit was operational (100 percent availability) but not in the manner in which it was designed (as discussed during the presentation of its performance curve, section 4.1.5).

4.2.7 Whirlwind W4

After some initial pump sizing problems, this unit was operational for the remainder of the test season. Since this was its first year of testing, an additional year is required before a more accurate measure of its reliability may be determined.

4.2.8 Windmotor

This was also the first year of testing for the Windmotor and thus few conclusions can be made on its reliability. Two weeks of operation were lost with intermittent pump problems. It was found that the cable which connected the rotor to the pump would shorten when it was turning at high winds; this appeared to result in the pump stator being jammed against the pump body. It is expected that this problem will be solved before the 1988 test season.

4.2.9 Environmental Systems Solar Pumper

Until near the end of the 1987 test season, this unit had been fully operational for two years. Three weeks were lost late in the test season due to the pump repeatedly losing its prime. If this problem can be corrected, it is expected this unit will continue to operate with complete reliability.

4.2.10 Campro Portable Solar Pumper

This unit has been installed on the test since 1984 and has operated without any maintenance for all four test seasons. This level of reliability assures that it will be a contender in the selection of remote water pumping systems.

4.3 System and Pump Efficiency Curves

The determination of system efficiency (Cp) and pump volumetric efficiency (Ve) are not requirements of the CSA performance testing standard. However, they do provide important information on the quality of the system's design. The system efficiency curves indicate what fraction of wind energy available to the wind turbine is actually utilized to pump water. The volumetric efficiency curves, for units with piston pumps, indicate the amount of leakage their valves allow

per stroke. Although work is not performed on water which leaks past the valves, the system will lose approximately the same amount to friction whether the pump operates at 100 or 70 percent volumetric efficiency. For this reason, the volumetric efficiency curve should be of interest to the wind pump manufacturers. The system efficiency and pump volumetric efficiency curves are presented in Figures 4.14 to 4.26. As with the performance curves, extrapolations which do not meet the CSA minimum data base requirement are indicated by a dashed line.

4.3.1 Wilks Cam 10

Figure 4.14 illustrates the Wilks Cam system efficiency up to the point that the pump yielded a consistent output. The shape of the curve is typical of multi-blade windmills equipped with piston pumps. It shows that once the unit overcomes the start-up torque, it quickly achieves its peak efficiency. From Figure 4.15 it can be seen that this peak also coincides with the pump's peak volumetric efficiency. The rapid decrease in pump volumetric efficiency indicates the pump begins to have valve problems in wind speeds above 5 m/s.

4.3.2 Chinook 7.5

The Chinook's system efficiency (Figure 4.16) is one of the best of the turbines tested in 1987. Like the Wilks Cam, it reaches its peak shortly after cut-in. This indicates it is making maximum use of the energy available from the lower speed winds (less than 5 m/s). The volumetric efficiency curve (Figure 4.17) indicates the pump provides consistently high performance throughout the mill's operating range.

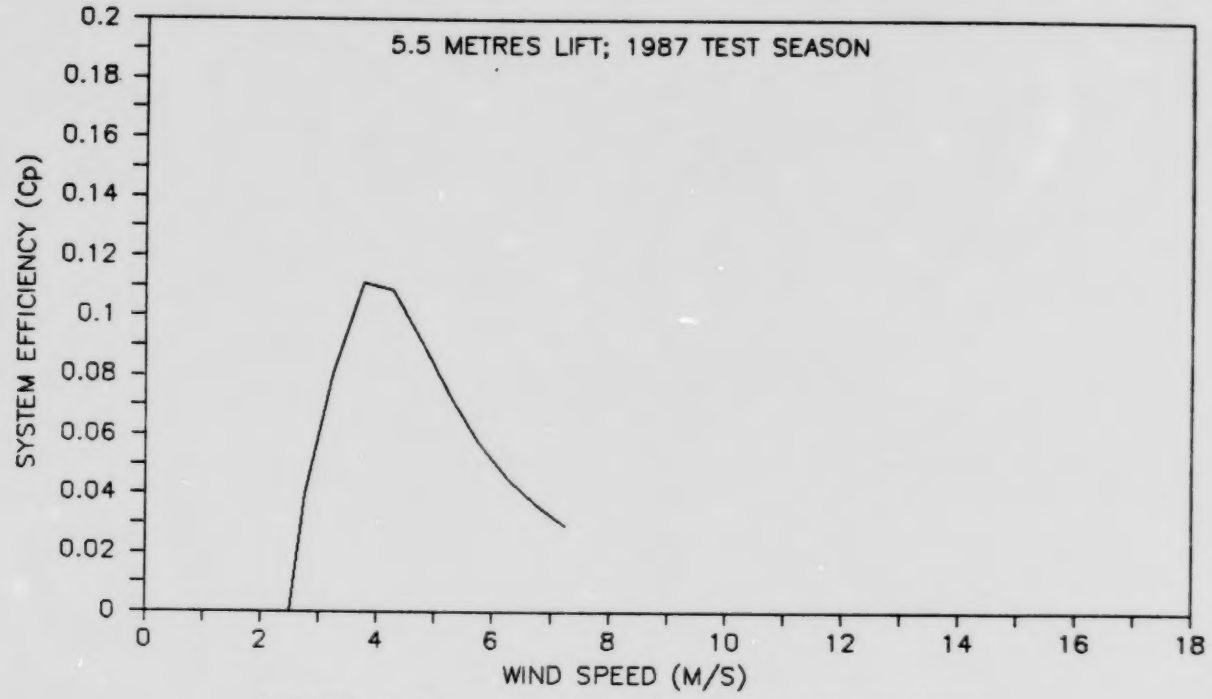

FIGURE 4.14 – WILKS CAM SYSTEM EFFICIENCY

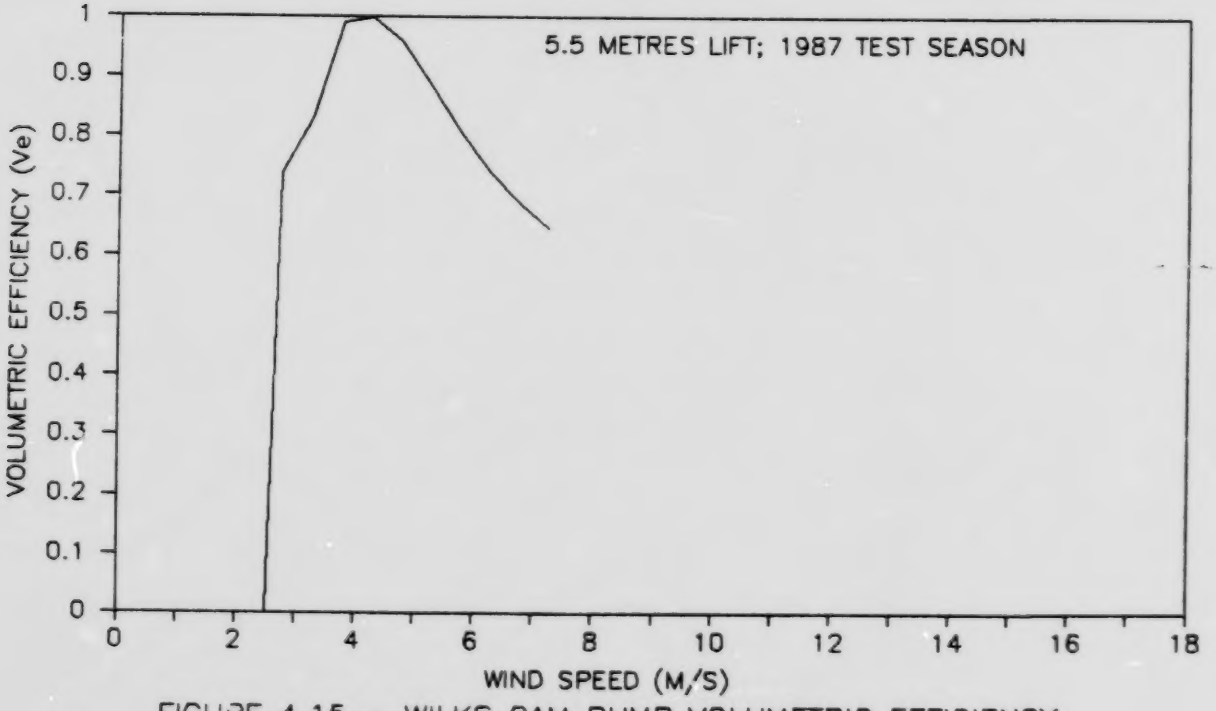

FIGURE 4.15 – WILKS CAM PUMP VOLUMETRIC EFFICIENCY

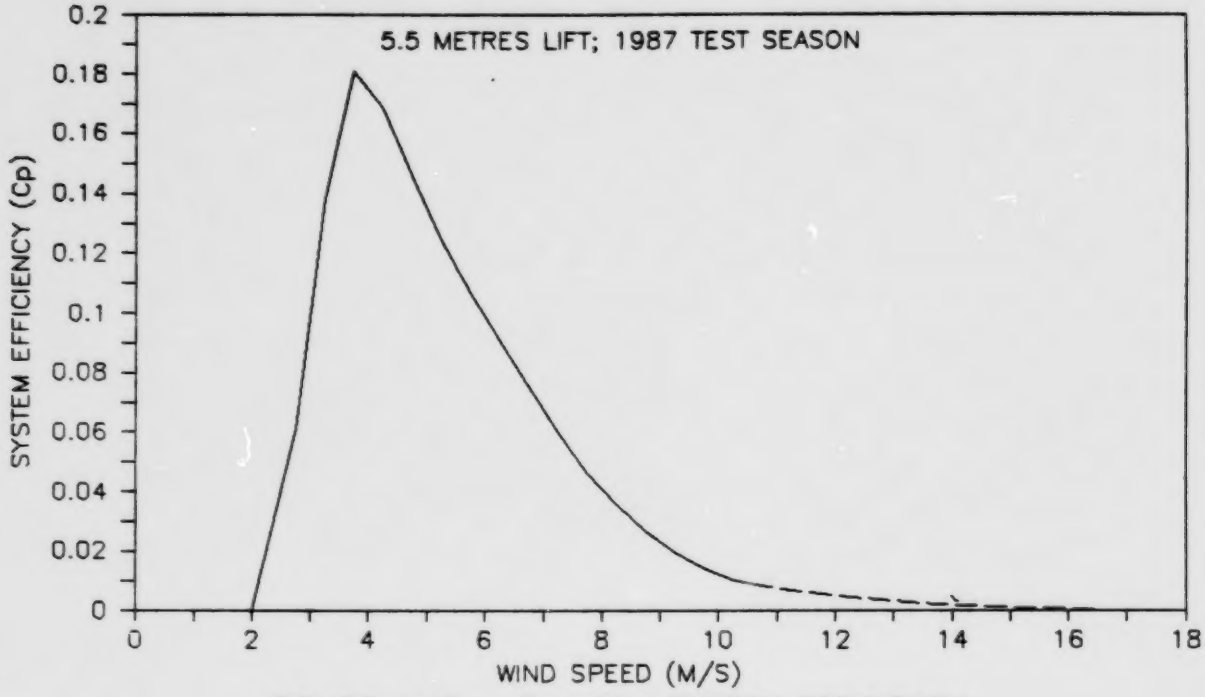

FIGURE 4.16 – CHINOOK SYSTEM EFFICIENCY

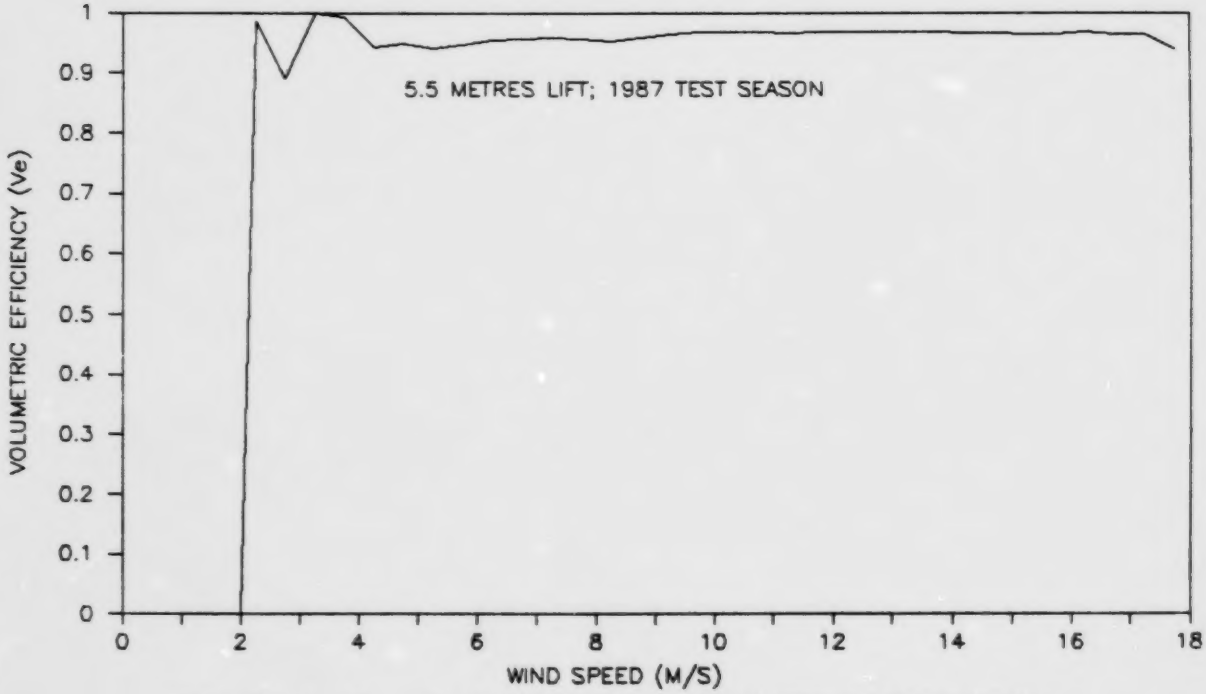

FIGURE 4.17 – CHINOOK PUMP VOLUMETRIC EFFICIENCY

4.3.3 Bowjons

Neither Bowjons use piston pumps to deliver water, thus only their system efficiencies are presented in Figures 4.18 and 4.19. Also, since their system efficiencies are so much lower than the previously discussed units, they have been plotted at a different scale. The figures show that the air lift system Cp is lower than that of the diaphragm system. Since the two machines have unique rotor and pump system configurations it is not possible to determine the source of the differences in the Cp curves. Generally, air lift systems have poor Cp characteristics because of the inefficiencies of using air infusion as a method of pumping water. The lack of efficiency in both these systems is counteracted to a degree by the fact that neither system would be damaged if the supply water became unavailable (eg. if a well was drained completely).

4.3.4 Deltx WP-20

The Deltx WP-20 achieved the highest system efficiency of the pumping systems tested (Figure 4.20). Using the hydraulic drive system, it had a peak that was only ten percent less than the previously tested direct drive system (Baker, 1987). Although the peak efficiency decreased, the cut-in wind speed also decreased from 4.25 m/s to 3.5 m/s. Thus, the system would capture a greater amount of energy in low wind speed regimes.

Figure 4.21 shows that the operation of the dual pumps did not achieve their peak efficiency as quickly as the Wilks Cam or Chinook systems. The pumps' volumetric efficiency above 7 m/s, however, was maintained at a respectable 85 to 90 percent. It is possible that the flow rates experienced below 7 m/s did not result in either complete or rapid valve closures. This may have been due to the unique design of the piston pumps which use neoprene as their valve material.

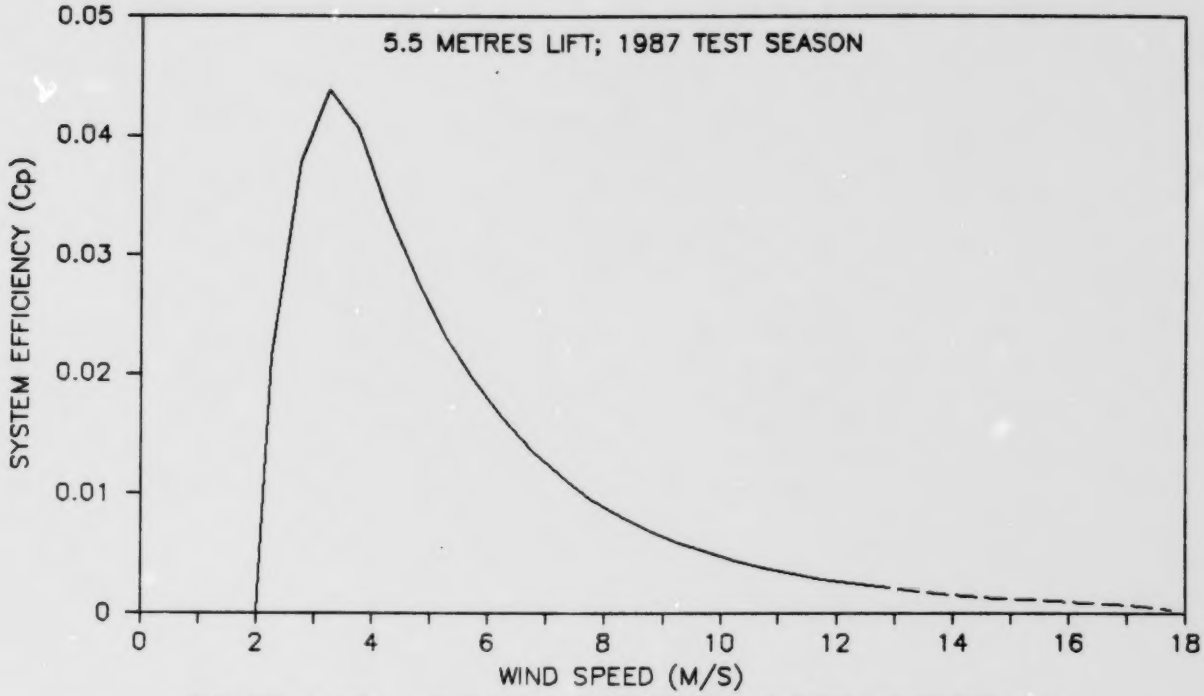

FIGURE 4.18 – BOWJON DIAPHRAGM SYSTEM EFFICIENCY

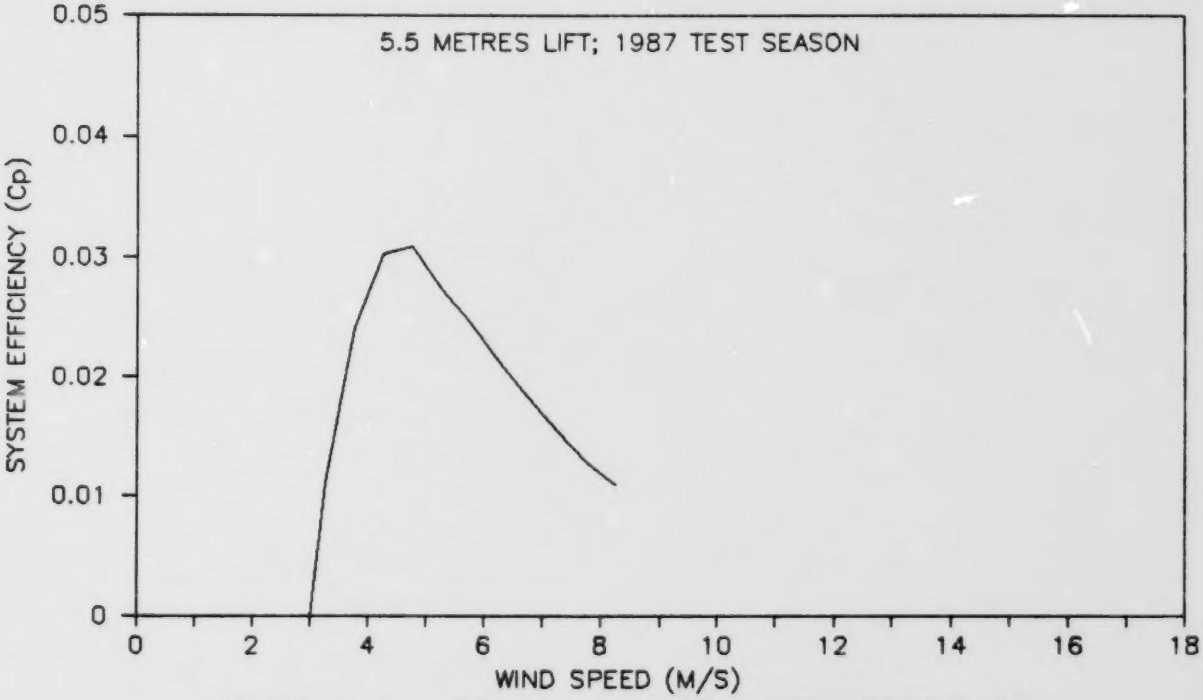

FIGURE 4.19 – BOWJON AIR LIFT SYSTEM EFFICIENCY

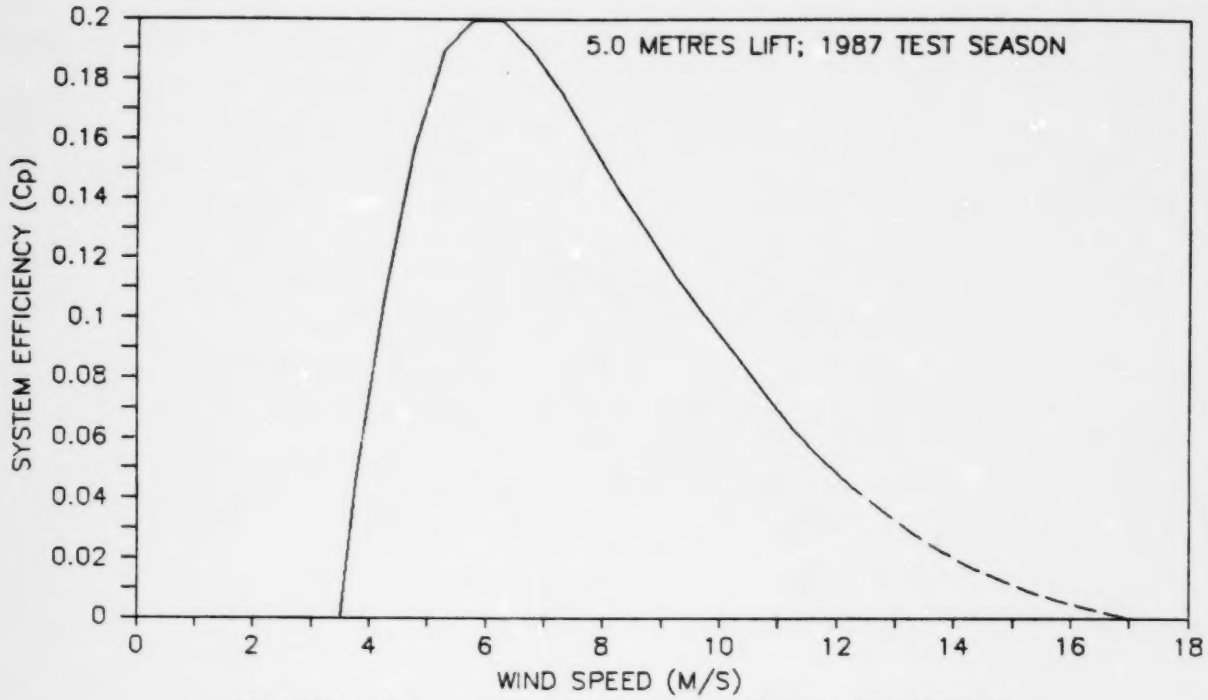

FIGURE 4.20 – DELTX WP–20 SYSTEM EFFICIENCY

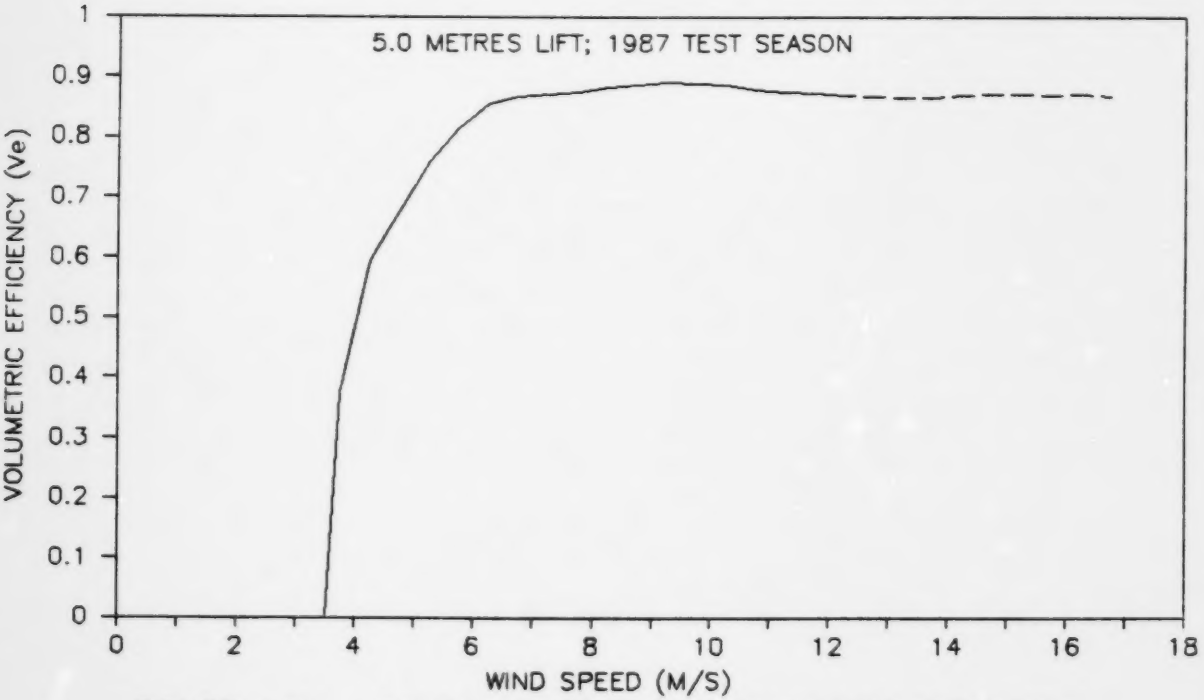

FIGURE 4.21 – DELTX WP–20 PUMP VOLUMETRIC EFFICIENCY

4.3.5 Maestro

The system efficiency of the Maestro is plotted in Figure 4.22. The Maestro's Cp is maintained near its peak over a wide range of wind speeds. This is believed to be symptomatic of the batteries providing short term storage. As this unit is further developed, it is expected that this Cp curve will change dramatically. In fact, if it operates in the manner in which it is designed, it will be impossible to generate a system efficiency versus wind speed curve. It is hoped that separate monitoring of the unit's components (eg. rotor power output, battery power output) during 1988 will assist the manufacturer in optimizing his design.

4.3.6 Whirlwind W4

Like the Maestro, the Whirlwind is also a wind electric unit. Its Cp curve (Figure 4.23) is shifted to the right compared to the multi-blade units because of its higher cut-in wind speed. As a result, it operates with a greater efficiency than all but the Deltx WP-20 between winds of 7 and 10 m/s. This is expected as rotors on high-speed electric units generally require high wind speeds to begin operating, but once operating they are typically more efficient than multi-blade rotors. It remains to be seen if the match between the rotor/generator and the control/pump system can be optimized further to make up for its relatively high cut-in wind speed.

4.3.7 Windmotor

The system efficiency curve of the Windmotor shown in Figure 4.24 does not have as sharp a peak as most of the pumping systems tested in 1987. This is a result of its self-regulating abilities which allow the machine's output to continually increase with increasing wind speed. The peak itself is much lower than the multi-blade units, most likely as a result of the blade design which captures only the wind

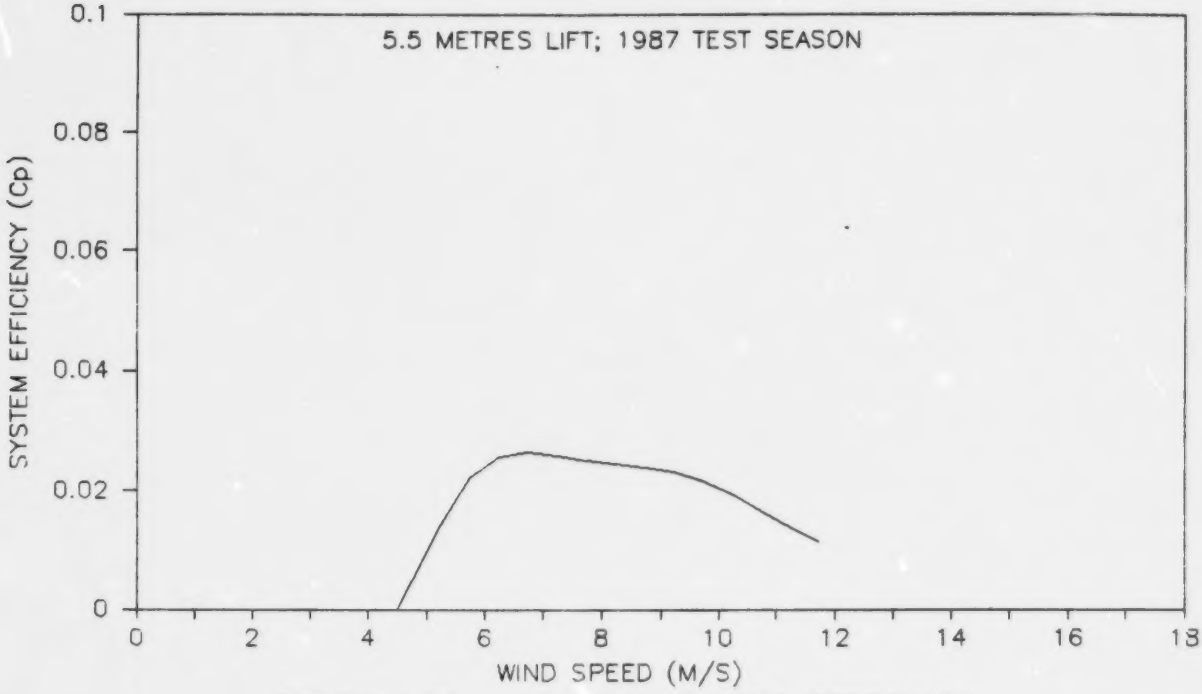

FIGURE 4.22 – MAESTRO SYSTEM EFFICIENCY

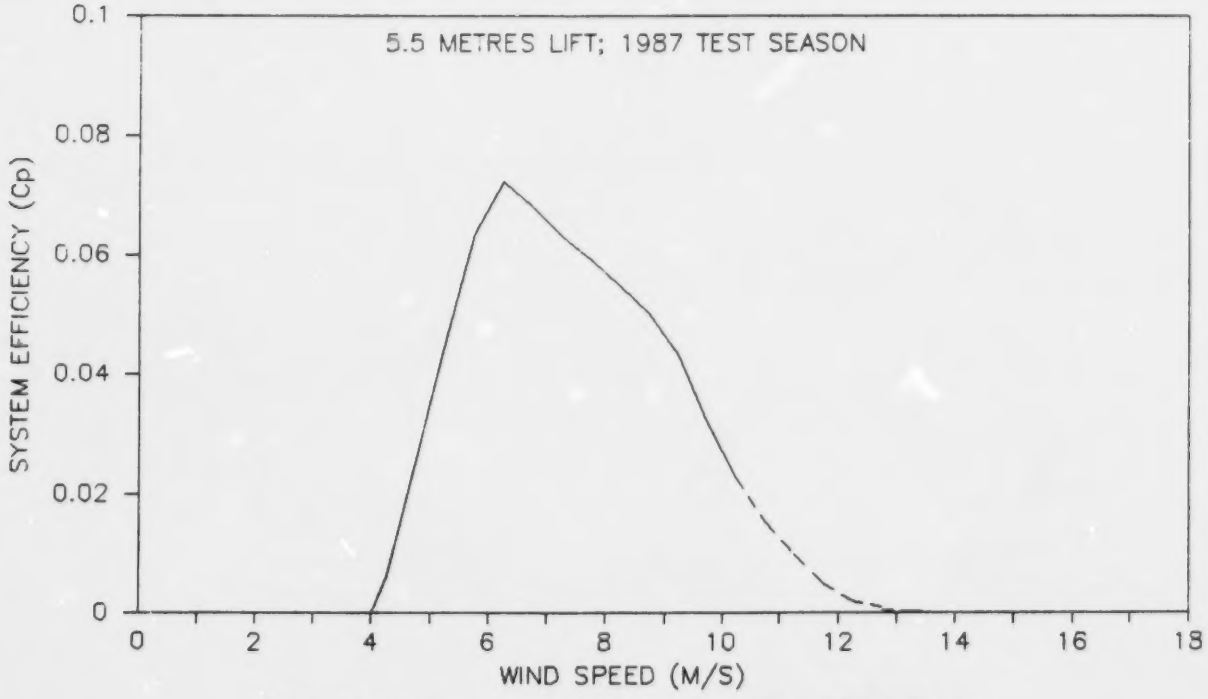

FIGURE 4.23 – WHIRLWIND SYSTEM EFFICIENCY

energy available at the perimeter of the rotor, and the helical pump which is not likely to be as efficient as direct-acting piston pumps.

Figure 4.25 illustrates the Windmotor's pump performance in relation to the volume it pumps per 100 revolutions. As mentioned previously, the pump is rated to produce 13.6 litres per 100 revolutions, which it does at approximately 6 m/s. Above this wind speed, the pump actually exceeds its production specification.

4.3.8 Solar Pumpers

The efficiency of the solar pumping systems in relation to the incident solar radiation on the panels is shown in Figure 4.26. A value of 1100 W/m^2 has the same energy content as a wind speed of 12.6 m/s in the Lethbridge area. Photovoltaic panels typically convert solar energy to electric power with a 7 to 14 percent efficiency. Therefore, if these panels operate as expected, the pump systems are operating with a peak efficiency of only 15 to 20 percent. As with the wind electric units, it is planned to monitor the voltage and current characteristics of the solar panels such that component efficiencies may be determined.

4.4 Monthly Pumping Yields

For wind pumping systems with sufficient data collected, monthly pumping potentials have been calculated. The calculation is based on the machine being fully operational throughout a 30 day month. The monthly wind speeds on the ordinate axes of Figures 4.27 to 4.30 are calculated from a wind speed distribution which is in the form of a Rayleigh distribution. The pumping potential at a specific site will vary depending on the machine's availability and the distribution of winds throughout the month.

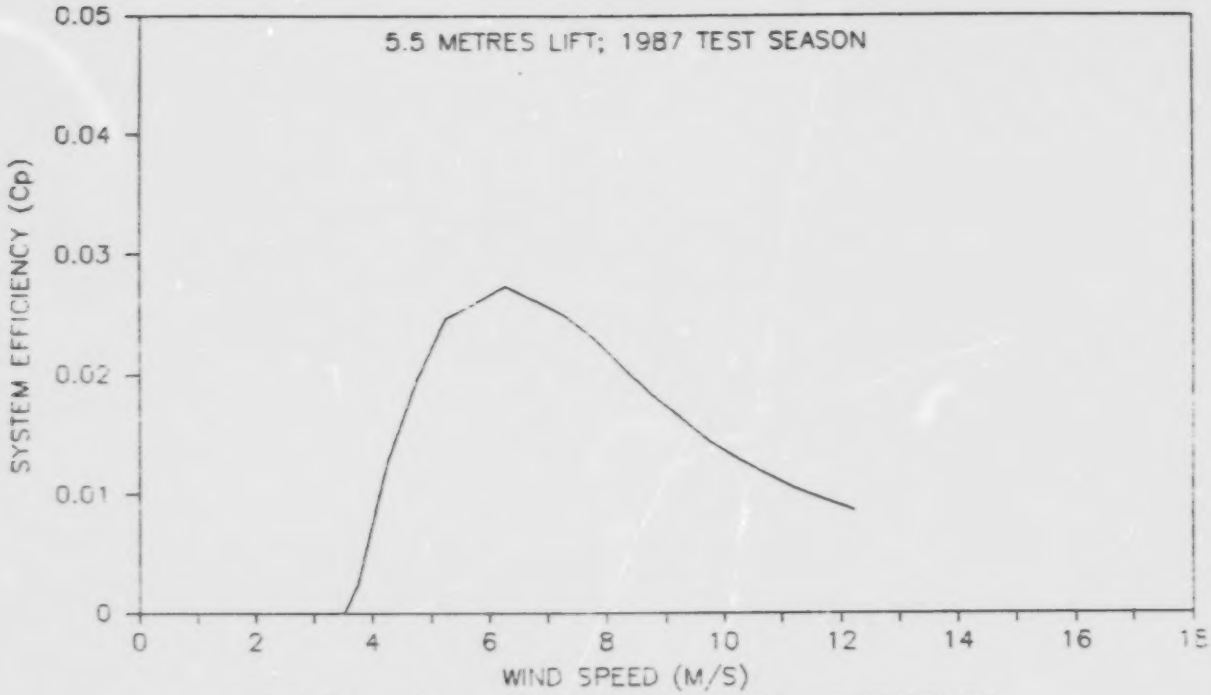

FIGURE 4.24 – WINDMOTOR SYSTEM EFFICIENCY

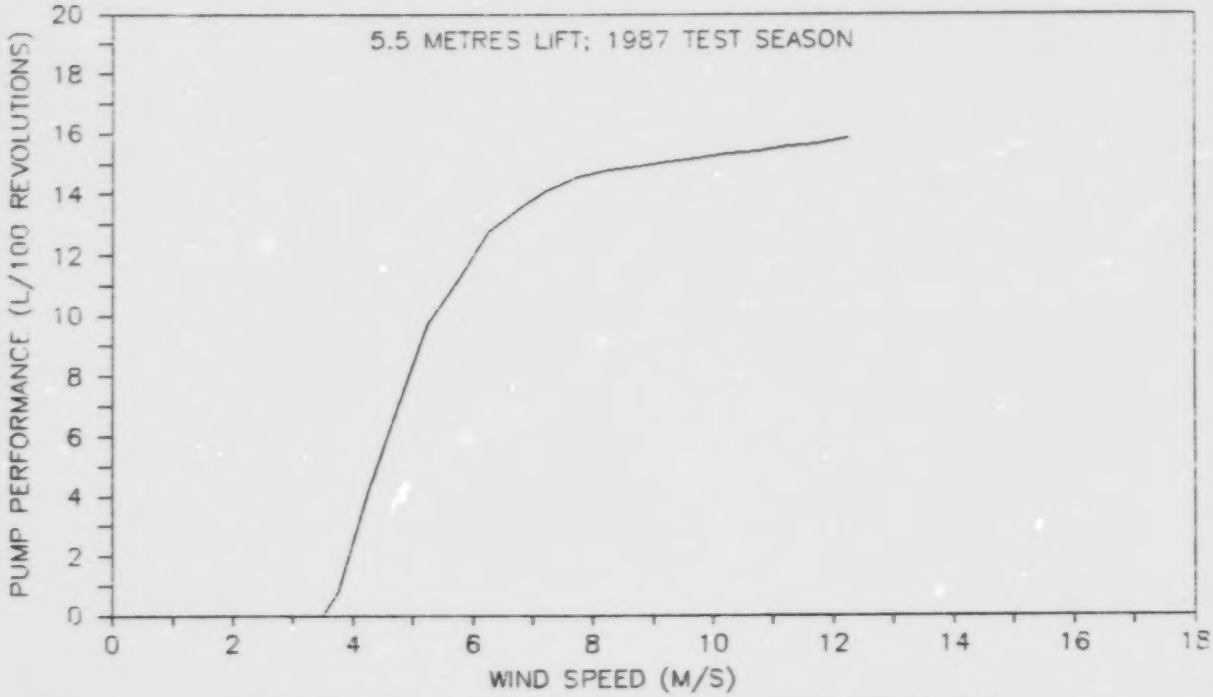

FIGURE 4.25 – WINDMOTOR PUMP PERFORMANCE

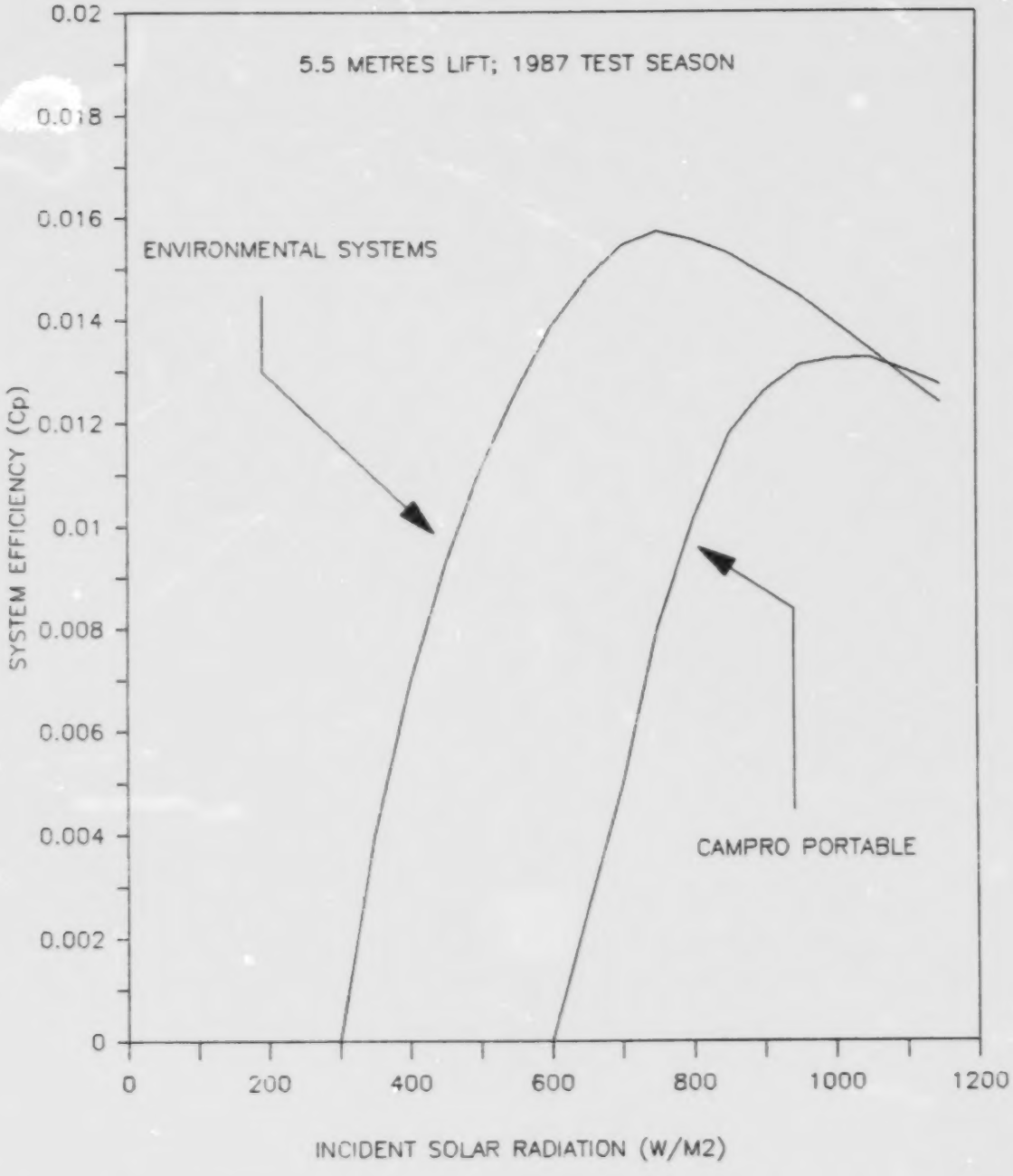

FIGURE 4.26 – EFFICIENCY OF SOLAR PUMPERS

4.4.1 Chinook 7.5

The Chinook's pumping potential increases rapidly as the monthly mean wind speed increases from 2 to 4 m/s. Above 6.5 m/s the monthly pumping potential begins to decrease. This is a result of increasing time spent with winds above 7 m/s (which corresponds to the Chinook's peak performance). Thus, the present configuration of this machine is most suitable for wind regimes with a mean wind speed below 6 m/s.

4.4.2 Bowjon Diaphragm

The Bowjon Diaphragm's monthly pumping potential is plotted in Figure 4.28. The monthly pumping potential continually increases with mean wind speed, illustrating the impact that higher furling and cut-out speeds have on the monthly pumping yield. As this curve is based on an extrapolation of the machine's performance above 14 m/s, the pumping yield may change slightly if the actual furling characteristics do not match the estimate.

4.4.3 Deltx WP-20

The monthly pumping potential of the Deltx (Figure 4.29) has been studied in previous publications (Baker, 1987). The hydraulic configuration tested in 1987 is capable of pumping 15 percent more water in a month with a mean wind speed of 4 m/s than the previous mechanical configuration. Since the peak performance of the hydraulic unit is 10 percent lower than the mechanical configuration, the increased yield can be directly attributed to the hydraulic unit's lower cut-in wind speed (reduced to 3.5 m/s from 4.0 m/s). However, the pumping yields presented on this graph will only be achieved when the reliability problems of this unit are overcome.

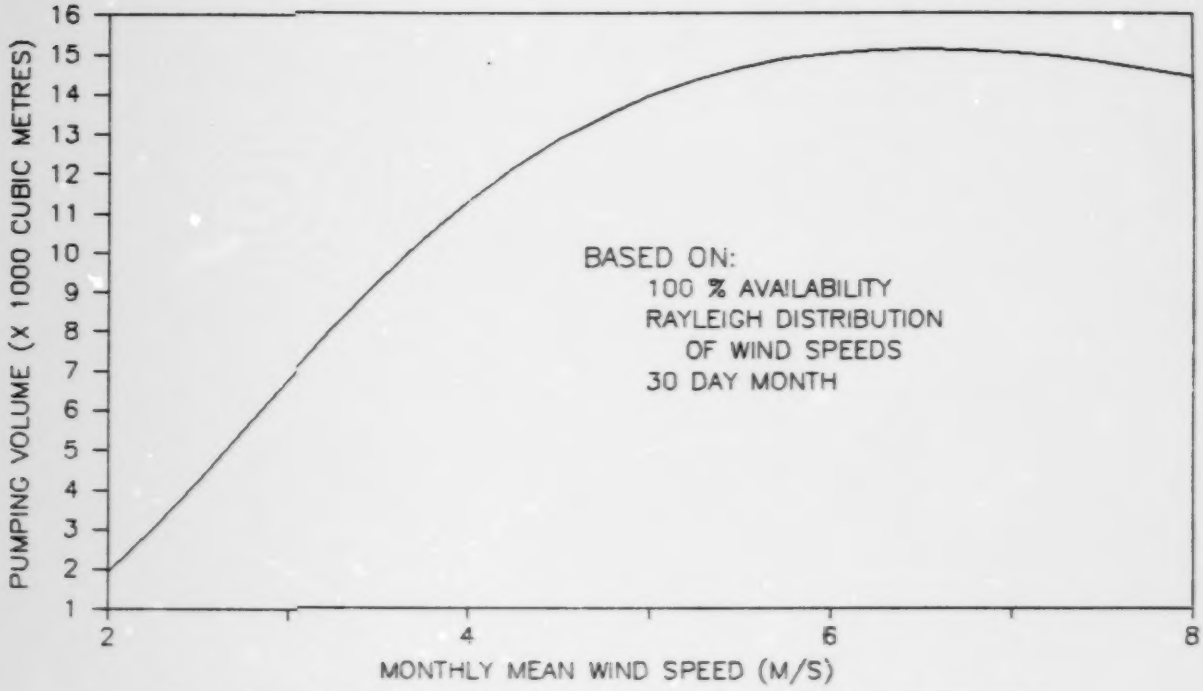

FIGURE 4.27 – CHINOOK'S MONTHLY PUMPING POTENTIAL

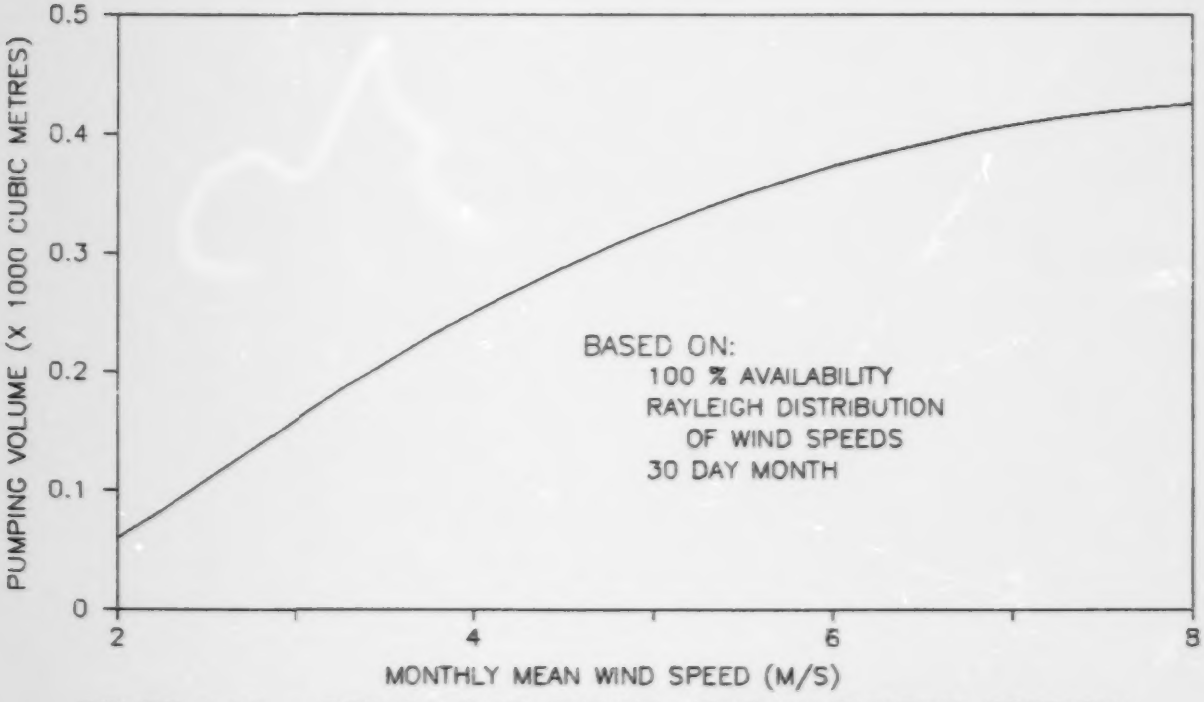

FIGURE 4.28 – BOWJON DIAPHRAGM'S MONTHLY PUMPING POTENTIAL

4.4.4 Whirlwind W4

The Whirlwind's pumping yield, shown in Figure 4.30, reaches its peak in a monthly wind speed of 7.5 m/s. In wind regimes with averages above this value, the increasing fraction of winds above 12 m/s (the speed at which the Whirlwind is almost fully shutdown by its control system) begin to negatively impact on the machine's pumping potential. The Whirlwind's pumping potential is discussed in more detail in the following section.

4.5 Optimization of Performance Curves for Peak Pumping Volume

An important consideration in the design of a water pumping windmill is the trade-off between maximizing the peak pumping rate and maintaining a low cut-in wind speed. If the peak pumping rate is maximized, the working parts are sized to run most efficiently in high winds. This inevitably results in either high torque requirements for start-up, or poor efficiencies at the lower wind speeds. Likewise, machines designed to operate in low wind speeds are normally not structurally strong enough to withstand high winds, and are therefore designed to furl at relatively low wind speeds.

Figures 4.31 and 4.32 illustrate the effect these two design philosophies have on the Whirlwind's monthly pumping potential. Figure 4.31 shows two hypothetical modifications to the Whirlwind's performance curve. The 'Improved Cut-in Speed' curve was created by shifting part of the system efficiency curve (Figure 4.23) 1 m/s to the left. The curve with 'Peak Output Maintained' would require the control system to restrict the rotor speed of the Whirlwind such that it resulted in a constant pumping rate during high winds. From Figure 4.31, one would expect that the 'Peak Output Maintained' curve would result in higher pumping volumes than the 'Improved Cut-in Speed' curve. Figure 4.32 confirms this, but only for regions where the monthly mean wind speed is greater than 5 m/s. During the summer months, even southern Alberta which is known for its high winds does

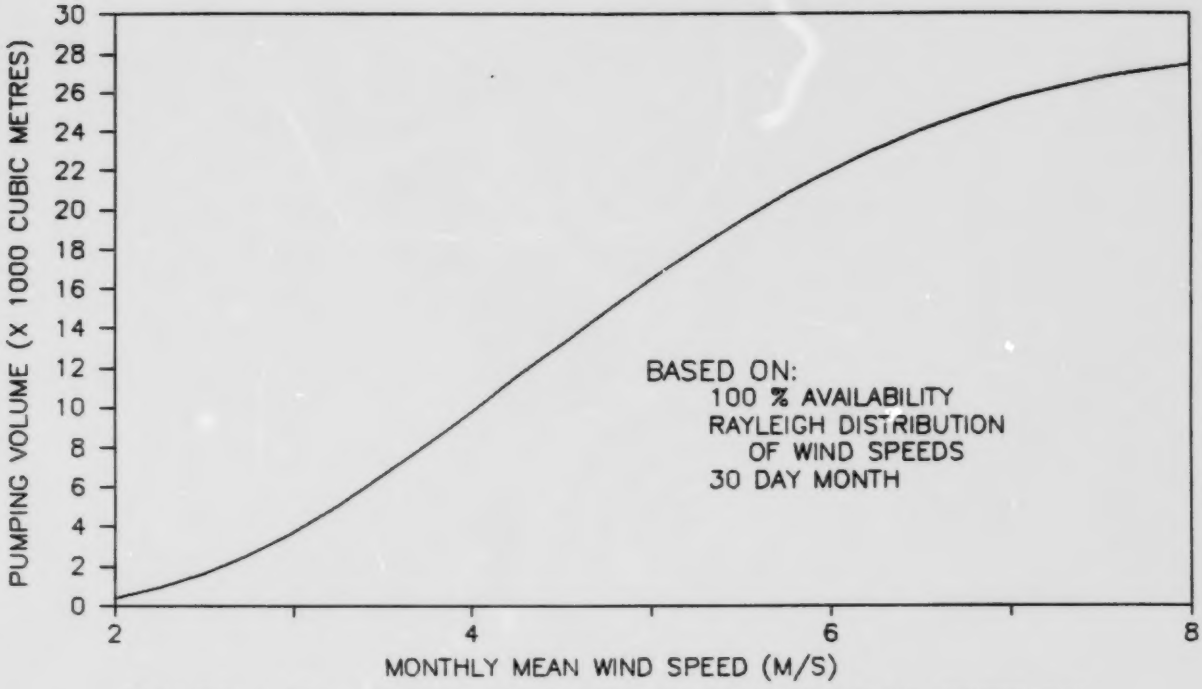

FIGURE 4.29 – DELTX WP–20'S MONTHLY PUMPING POTENTIAL

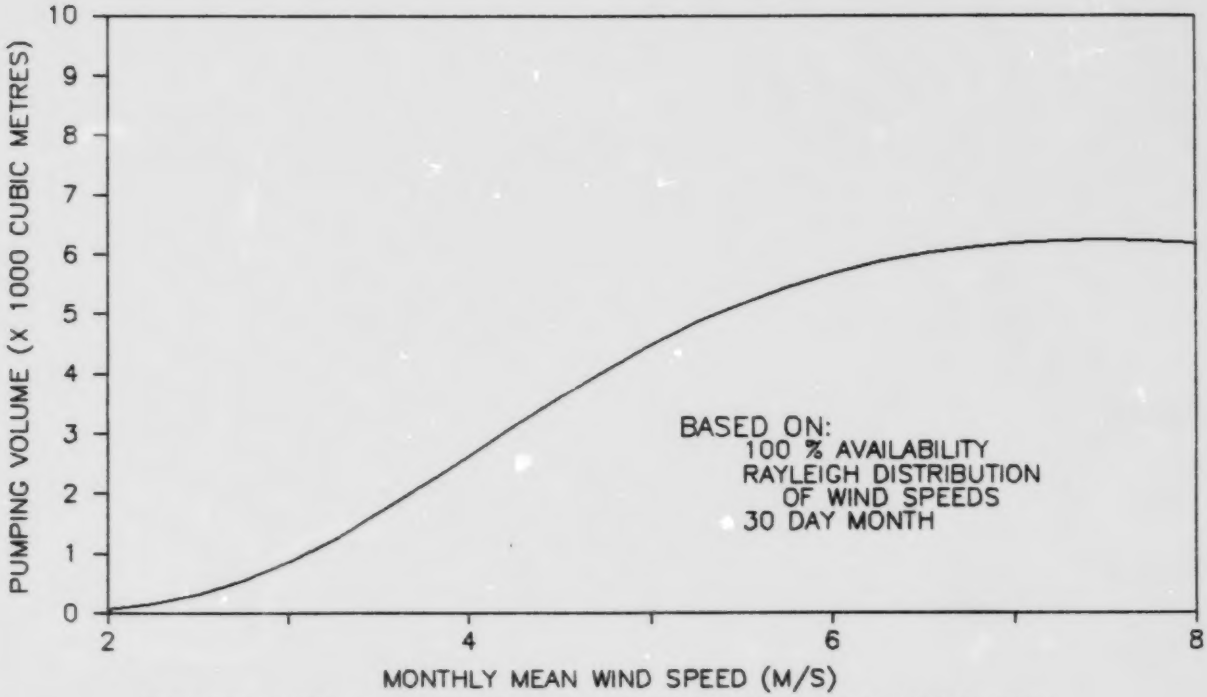

FIGURE 4.30 – WHIRLWIND'S MONTHLY PUMPING POTENTIAL

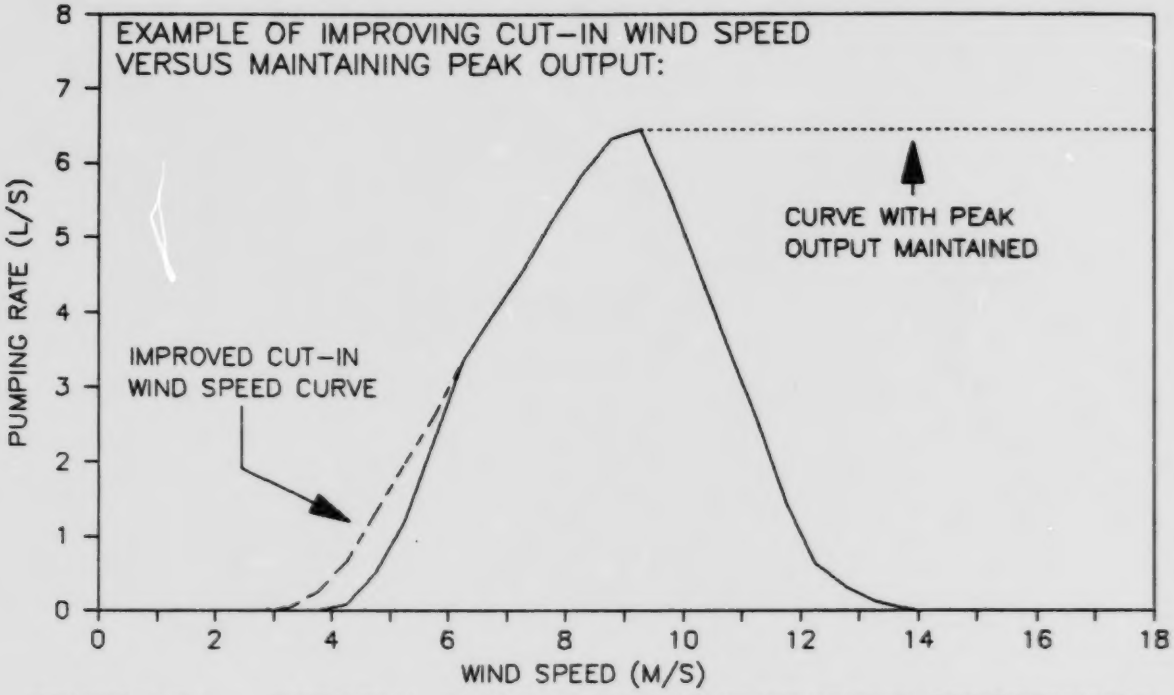

FIGURE 4.31 – POTENTIAL CHANGES TO THE WHIRLWIND'S PERFORMANCE

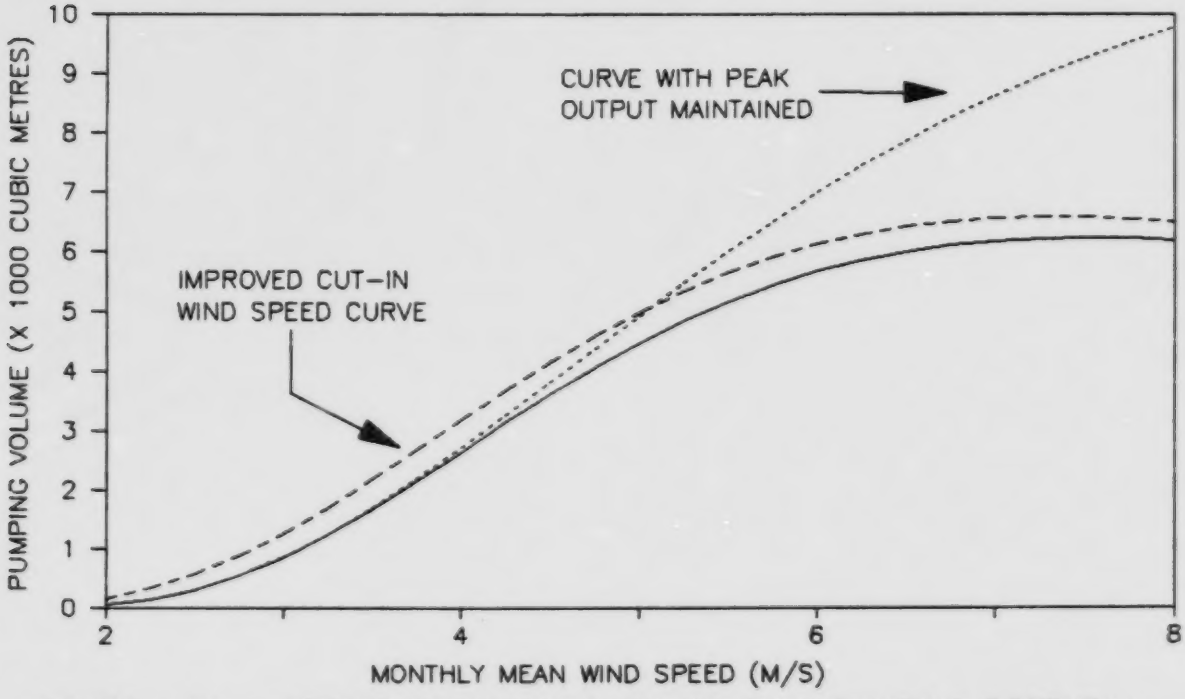

FIGURE 4.32 – EFFECT OF CHANGES ON MONTHLY PUMPING POTENTIAL

not maintain monthly averages above 5 m/s. For example, the average wind speed in Lethbridge during July and August is 4.7 m/s (Environment Canada, 1982). Thus, the Whirlwind would benefit more by decreasing its cut-in speed by 1 m/s than by modifying its control system to maintain a constant output during high wind speeds. This result, that a low cut-in wind speed is more beneficial than a high furling speed, has been observed in several of the previous LWRTS studies (Baker, 1987, Paterson et al, 1985).

II

WELL SIMULATOR

WELL SIMULATOR

5.0 INTRODUCTION

The low-head testing program has proven very successful, with the steadily increasing interest shown by manufacturers and potential buyers in the performance data generated from the site. Canadian International Development Agency (CIDA) officials have confirmed interest in incorporating proven Canadian wind pump technology into third-world aid projects (Chappell, 1986). Other potential export markets have been identified as evidenced by the recent installation of a Chinook water pumper in the Caribbean.

To assist this market development, it became apparent that a method was needed to better match turbine and pumps. The most common problem with nearly all of the water pumping wind turbines tested at the site is the matching of the wind turbine with the right pump system for specific applications. In the past, unless the application was of the low-head variety (cattle watering, subsurface drainage), the site was unable to assist the manufacturer in testing his proposed configuration. The manufacturer then exposes himself to great risk, especially in export sales, if he ships the system without first locally testing it in the configuration in which it will be installed. There is also the risk of over or underselling a system by assuming that the water production of the system varies inversely with the pumping head. Although this may be true for some pumps, the Lethbridge Wind Research Test Site has found that most water pumpers do not obey this axiom.

Based on these findings, the Lethbridge Wind Research Test Site has developed a well simulator which can be attached to the wind turbines to realistically test these machines at various well depths.

6.0 SIMULATOR DESCRIPTION

The well simulator was designed with the following objectives in mind.

Design Objectives:

1) Simulate well depths of 15 - 250 m.
2) Allow the separation of component efficiencies.
3) Meet CSA standards accuracy requirements.
4) System must be portable.

Application Objectives:

1) Assist domestic manufacturers in optimizing wind turbine systems for various wind regimes and well depths.
2) Assist in development of local and export wind pump markets by demonstrating and collecting performance data under conditions similar to potential installations.
3) If necessary, be able to provide certification capabilities.

The final design was the result of first studying the many well simulators which have been built by other groups in the past (Herrmann, et al., 1986; McKenzie, 1985; Pulfrey, et al., 1986). The final design, shown in Figure 6.1, controls the working pressure by maintaining a constant pressure within a vessel. The pressure in this vessel acts on the water within a standpipe upstream of the control valve. The pump must overcome this pressure to deliver water to the standpipe. If the control valve remains closed, the water fills the standpipe causing an increase in pressure due to decreased volume available for the compressed air. By attaching a proportional/integral level controller, the level in the standpipe is maintained at a set point provided by the operator. The controller averages the error from the set point over a fifteen-second period and adjusts the opening of the control valve accordingly. This results in smoothing the pulsating input of piston pumps to a continuous flow output. To allow for quick increases or decreases in flow caused by gusts, the standpipe was sized such that the increase in water volume delivered before the controller can react, will always be less than three

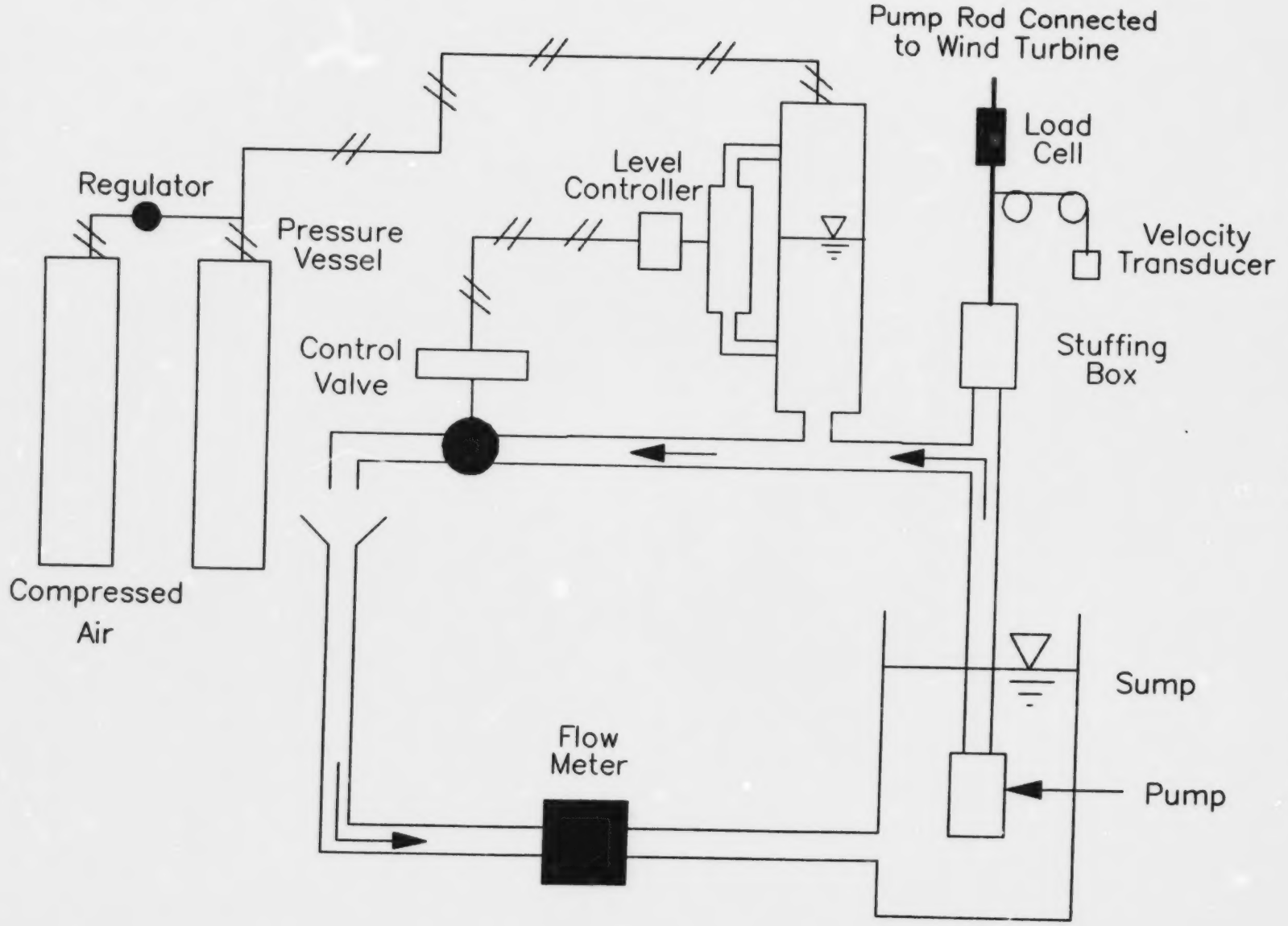

Figure 6.1 Design of Well Simulator

percent of the pressure vessel. Thus the pressure in the system never fluctuates more than three percent from its set point. Finally, the regulator from the compressed air tank provides make-up air for any air which dissolves into the water and allows for simple and quick adjustments to the test pressure.

Simulation of the working pressure is not the only parameter which must be considered in designing a well simulator. The effects that the long sucker rod and water inertia may have on performance in deep wells must also be considered. For deep well applications (greater than fifty metres) using piston pumps, it is proposed to simulate the pumping rod's weight and elastic properties with a weight and rubber flange system. The significance of this parameter will be studied over the 1988 test season to determine if a method of simulation is required and how it may be achieved.

To separate the component efficiencies, the force applied to the pump is integrated with the velocity of the sucker rod to determine the power delivered to the pump. The efficiency of the rotor is then the difference between the energy supplied by the wind (monitored by anemometers, atmospheric temperature and pressure sensors) and the energy supplied to the pump. The pump efficiency is calculated by comparing this input energy to the output water energy (Section 3.2).

7.0 PRELIMINARY RESULTS

Two of the water pumping windmills tested in 1987 were also connected to the well simulator. Since no modifications were made to the windmills, the simulator was set to a pressure equivalent to 20 metres of lift. The simulator has since been used throughout the winter by the Prairie Agricultural Machinery Institute (PAMI) in Lethbridge to test a number of positive displacement pumps. One of their reports has been included in Appendix C. The windmills tested on the site in 1987 did not have the velocity/force instrumentation attached which would enable the separation

of rotor and pump efficiencies. This instrumentation has been supplied to PAMI to confirm its operation over the winter months. The performance results of the machines tested during the summer are presented below.

7.1 Wilks Cam 10

The performance characteristics previously presented for the Wilks Cam are compared with its performance at 20 metres of lift in Figure 7.1. The results show the importance of the well simulator. It would have been impossible to predict that the windmill when operating against a 20 metre lift would actually outperform its pumping rate at 5.5 metres lift (in wind speeds above 7 m/s). It is believed that the back pressure at 20 metres lift causes the centre valve in the piston pump to close properly. Until the pump is repaired such that it will operate properly at 5.5 metres lift, the relationship between the pump head and the pumping rate cannot be determined. The curves do indicate the effect the increased head has on the cut-in wind speed. As discussed previously, the increase in cut-in wind speed from 2.5 m/s to 4.5 m/s will have a significant impact on the units monthly potential pumping volume.

7.2 Whirlwind W4

Figure 7.2 combines the Whirlwind's performance curve at 5.5 metres lift with the ten-minute average data points collected when this system was tested with the well simulator. The well simulator data, although insufficient to draw performance conclusions, illustrates a number of points. At 20 metres lift it was found that the wind turbine would begin turning at roughly the same wind speed, but the pump would only reach sufficient RPM to overcome the pumping head at wind speeds above 8 m/s. The system would then operate in winds down to 6 m/s. Unfortunately, if the winds increased after cut-in to 9 or 10 m/s, the logic controller would shut down the turbine. This narrow range of operation, coupled with the cyclic operation of the

controller, resulted in the wide amount of scatter seen in the raw data. Also, without the simulator it would be much more difficult to predict the new cut-in wind speed and discover that the logic controller cycling would have such a detrimental effect on the performance of the machine. It is clear from this limited amount of data that further testing with the simulator will be essential to select a more suitable pump size for high lifts.

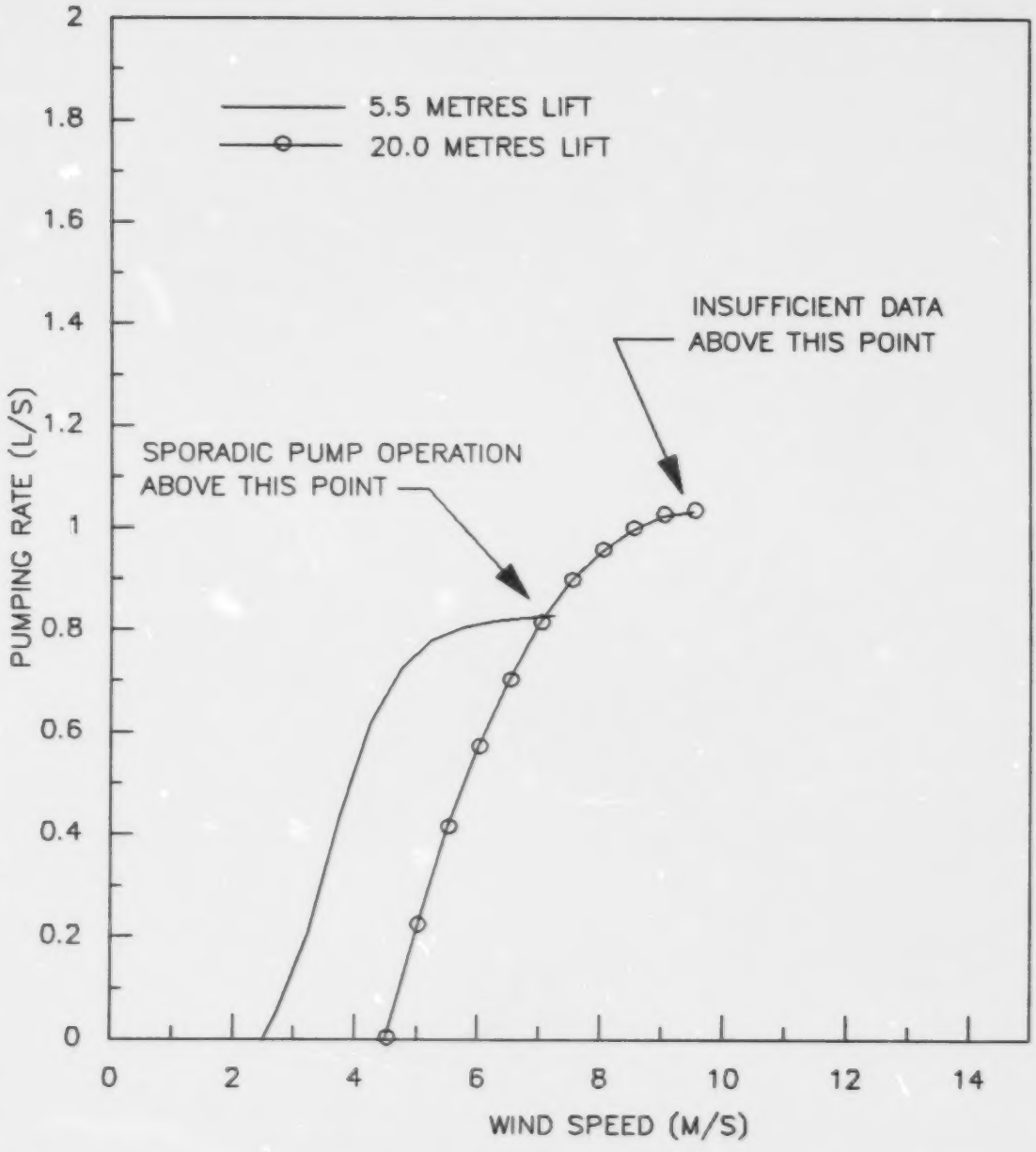

FIGURE 7.1 – WILKS CAM PERFORMANCE AT 20 METRES LIFT

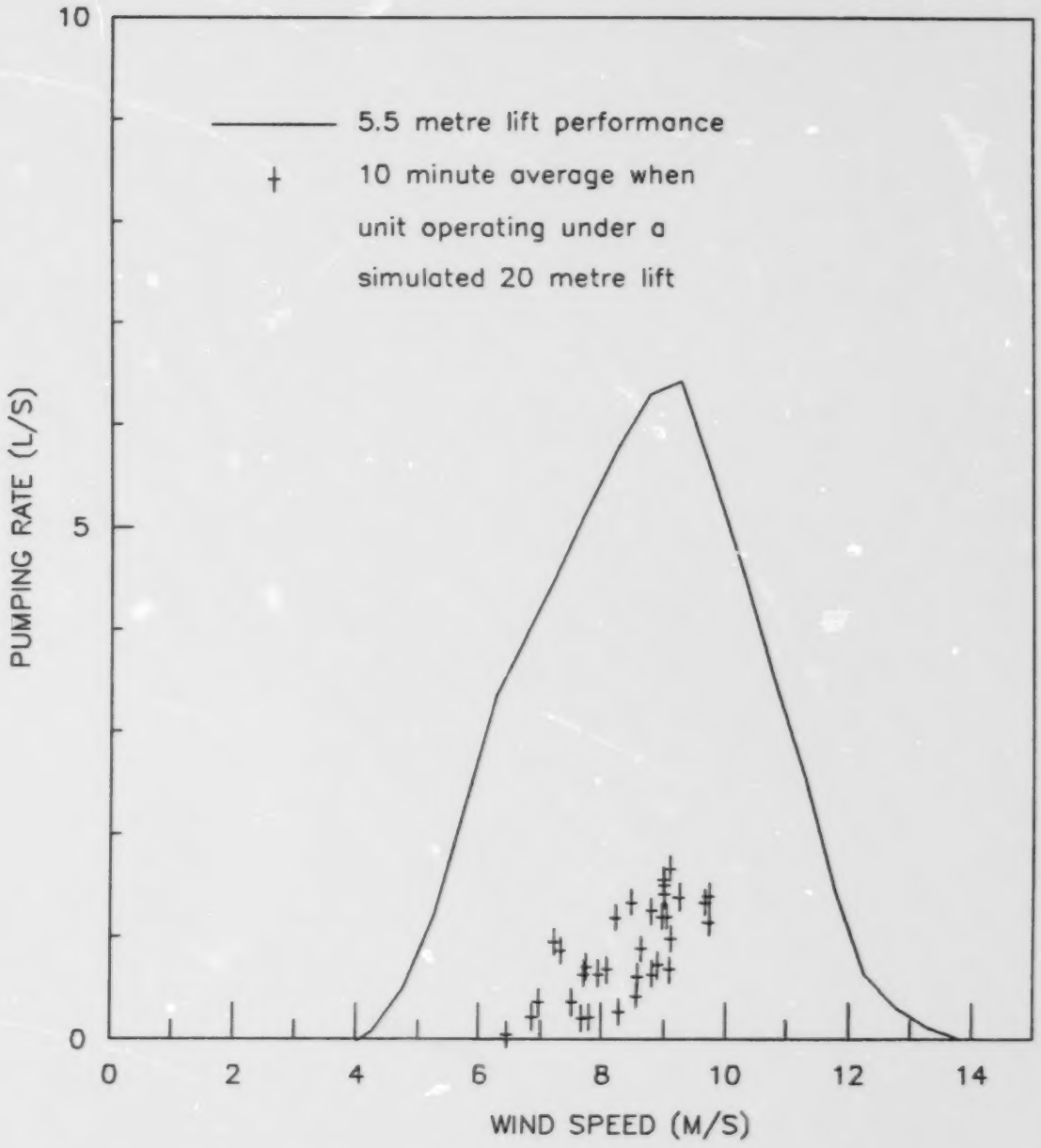

FIGURE 7.2 – WHIRLWIND PERFORMANCE AT 20 METRES LIFT

III

APPLICATIONS & MARKETS

APPLICATIONS AND MARKETS FOR WINDPUMPS

8.0 INTRODUCTION

As mentioned previously, the original objective of the Lethbridge Test Site was to evaluate the suitability of wind energy for low lift drainage pumping in Southern Alberta. Subsequent investigations have revealed other equally attractive markets. Following are some examples which illustrate the wide range of market opportunities and pumping requirements. It is essential for a wind pump supplier to carefully identify suitable applications of his equipment to ensure that he targets the most appropriate markets and avoids overselling his equipment.

8.1 Example 1 - Land Drainage

Figure 8.1 illustrates a conceptual application of a wind pump for low lift drainage pumping. Outflow from a subsurface drainage system is collected in a small holding pond for pumping into an adjacent canal. Measurement of the discharge from a 5 ha site near Lethbridge showed a flow of 0.20 l/s, rising to 1.5 l/s after irrigation. The maximum volume to be pumped is 1100 m^3 per month during the irrigation season. A typical lift would be 5 to 6 m to provide discharge into the canal. Of the wind pumps tested in 1987 the Deltx, Chinook, Wilks, Maestro and Whirlwind have potential capacities to match this application. The smaller machines, the Maverick and Bowjons, would require more than one unit to provide adequate capacity.

8.2 Example 2 - Watering Livestock from Dugouts

Thousands of farms and ranches in the Great Plains region of Western Canada and the U.S.A. depend upon collection of runoff in excavated dugouts as a source of water for livestock. Typically, the cattle are allowed direct access to the dugout for drinking. This

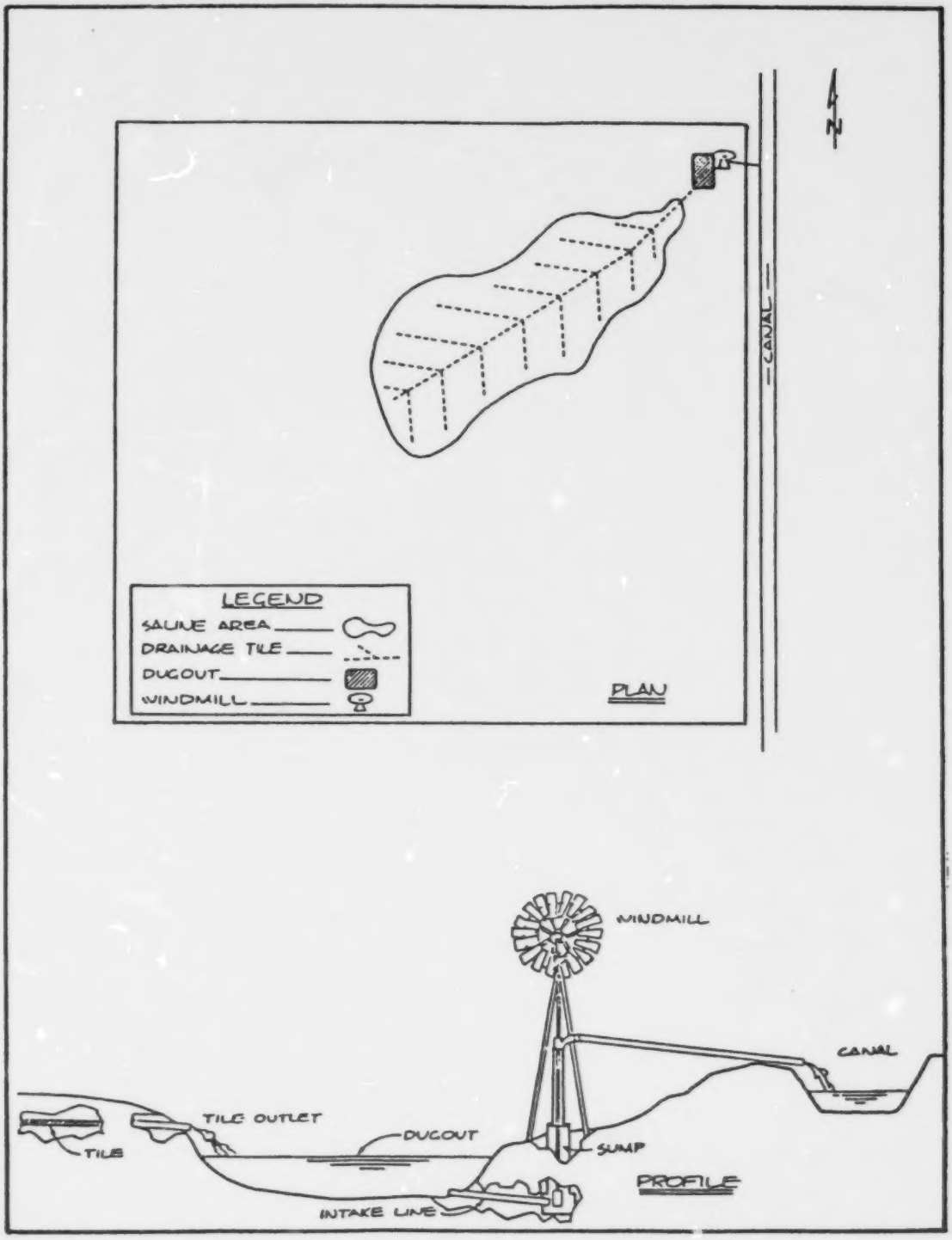

Figure 8.1 Schematic diagram of windpump application for low-lift tile drainage outlet.

practice often damages the earthen banks, increases the maintenance of the dugout and may contaminate the water supply. Cattle also risk drowning by falling through ice on the dugout surface. Therefore, a significant market exists for a reliable, low-cost system to pump water from a fenced dugout into an adjacent storage tank and watering trough. Figure 8.2 shows a typical installation using an air lift windpump. Configurations for other types of windpumps would be similar except they may need to be located directly over the sump if utilizing conventional piston-type pumps.

A typical water requirement for range cattle is 54 litres per cow per day. To supply 100 cows would therefore require 5400 litres per day or 162 cubic metres per month. All of the wind pumps tested in 1987 are theoretically capable of pumping this volume at a 5 metre head. This market will be captured by low-cost, reliable machines with a low cut-in wind speed. Cut-in speed is important because it determines the size of storage tank needed to provide water during periods when winds are too light to operate the windpump. Figure 8.3, derived from ten years of AES data, can be used to estimate the required storage period for three Alberta locations. As shown, a turbine with a cut-in wind speed of 4 m/s would require 100 hours more storage capacity than a turbine with a cut-in wind speed of 2 m/s. The added storage requirement (4 days x 5400 l/d = 21,600 litres) represents a significant extra cost to the farmer. Therefore, windpumps with low cut-in speeds have a definite advantage in this application. Intense competition is expected between windpumps and solar pumpers for this market.

8.3 Example 3 - Watering Livestock from Wells

At the 1987 Marketing Seminar held in Lethbridge a representative from the Prairie Farm Rehabilitation Administration (PFRA), of Agriculture Canada, reported that they are conducting a comparison of solar and wind energy systems for pumping water for livestock on their community pastures throughout the prairies. Presently, PFRA operates

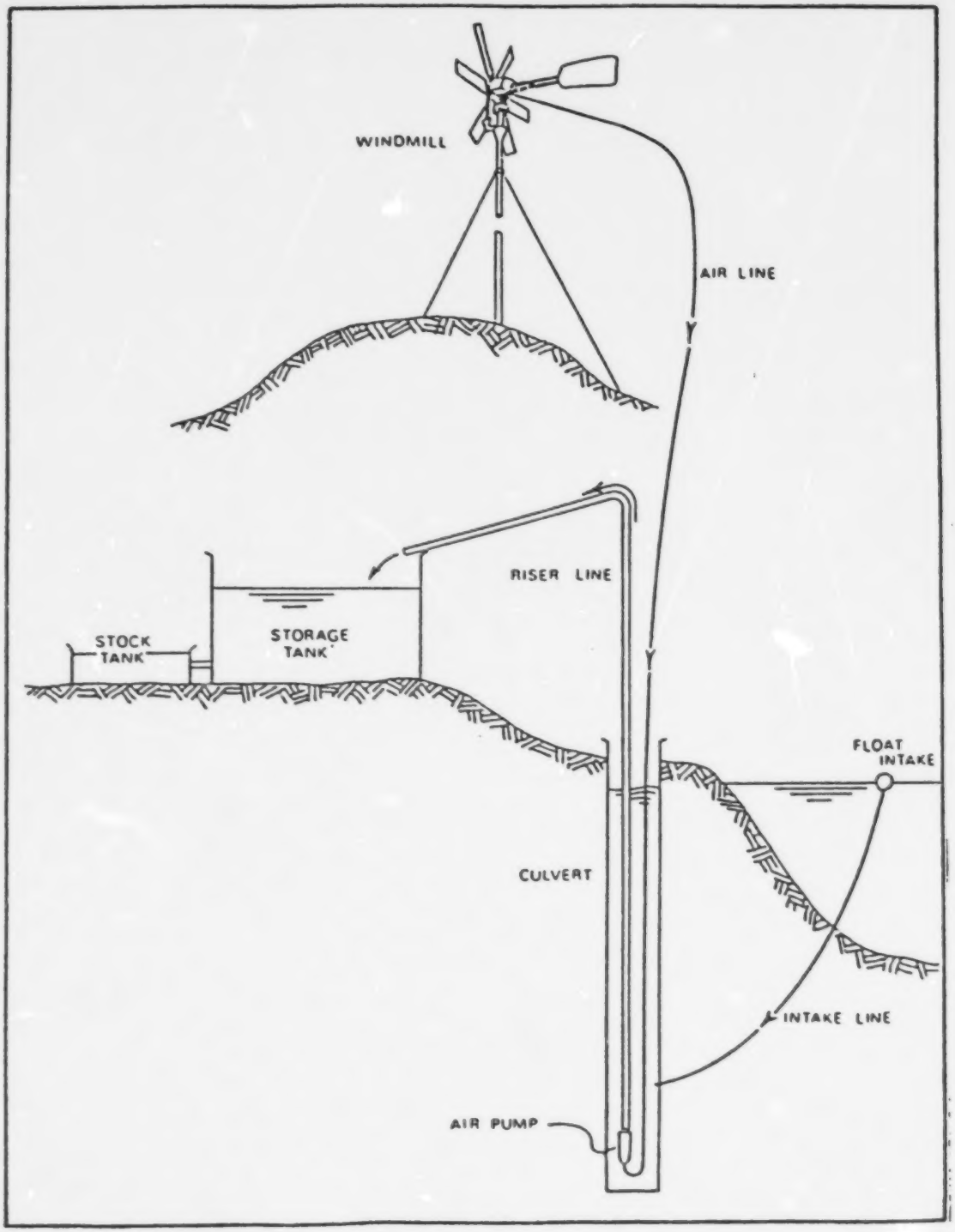

Figure 8.2 Schematic diagram of airlift pumping for livestock watering.

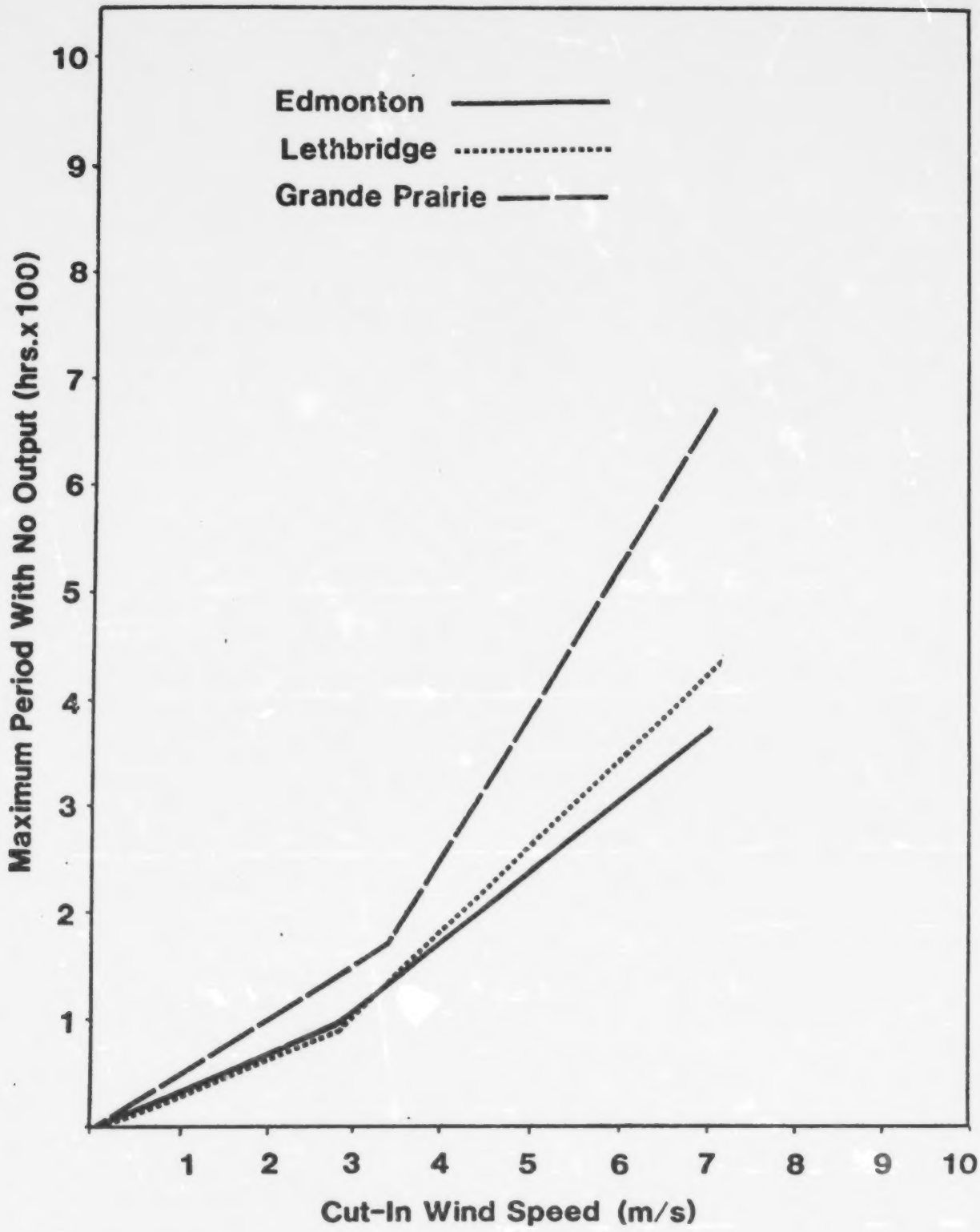

Figure 8.3 Maximum consecutive periods of calm for a range of cut-in wind speeds at three Alberta locations.

several hundred traditional windmills pumping from drilled wells, typically 10 to 50 metres deep. These wells are generally remote from electric power lines so they will continue to need renewable energy pumping systems. Many of the original mills are due for replacement either with wind or solar pumpers. As in Example 2 the continuous requirement for water makes a low cut-in speed important. It was also stressed that the projected maintenance cost will be a major factor in selection of replacement systems.

8.4 Example 4 - Wetlands Development

Ducks Unlimited Canada maintains several hundred projects in Western Canada which require low lift, high volume pumping to supply water to wetland areas. Typical pumping requirements against a 4 to 5 m head range from 30,000 to 150,000 m^3 to be supplied during the period of May to October. This represents an ideal application for wind energy because there is no daily pumping requirement. In other words, several days of low winds are acceptable provided the seasonal demand is met. Due to unsatisfactory performance of the first windpump purchased, Ducks Unlimited representatives have stated that they will not purchase any additional machines. However, they may consider contracting a windpump supplier to pump water at a negotiated price per m^3. Of the machines tested to date, only the Chinook 7.5 has pumped more than 30,000 m^3 in one test season. Several of the windpump suppliers are evaluating their potential to supply larger capacity systems as required for this application.

8.5 Example 5 - Export Opportunities

The island of Barbados has an estimated 800 abandoned wells which were pumped by wind power prior to installation of a pressured water system supplied by deeper, high-capacity wells. A predicted water shortage and high cost of electricity may make these wells attractive for rehabilitation and replacement of the windpumping systems. The

present cost of water from the main is $0.50 U.S./$m^3$ and electricity costs $0.175 U.S./kwh. A typical pumping requirement would be 1.5 l/s at a head of 50 m in a wind velocity of 4.5 m/s. The water would be used for small scale irrigation of vegetables and fruit trees, and possibly for fresh water fish production. In 1987 one of the Alberta windpump suppliers, Canadian Agtechnology Partners, installed a test machine for the Barbados Agricultural Development Corporation (Figure 8.4). Their goal is to evaluate the special requirements of windpump systems under tropical conditions in a developing country.

This example illustrates the potential value of the recently constructed well simulator. Beginning in 1988 the LWRTS will be able to determine if a given windpump system could meet the specifications for a particular application anywhere in the world, given the required flow, lift and available wind speeds.

9.0 ECONOMICS OF WINDPUMPING

The economic viability of wind energy for pumping water depends upon the capital and operating costs of a windpumping system compared to the cost of other available energy sources. In Western Canada the standard for comparison will usually be the cost of installing an electrical pump. For livestock watering or small-scale drainage the operating costs of a fractional h.p. electrical pumping system is seldom more than $100 to $200 per year. Assuming that this is approximately equal to the annual O & M cost on a small windpump, the economic analysis can be greatly simplified to a direct comparison of capital costs between the two systems. This means that the amount of investment a farmer may consider making in a windpumping system will be directly related to the cost of installing electrical power to the given site. Extension of power lines costs approximately $7000 per km. Therefore, any pumping site located greater than one km from a power line could be a potential application for a small windpumping system costing $4000 to $5000 installed. However, before making a decision in favor of the windpump, the investor would have to be convinced that it

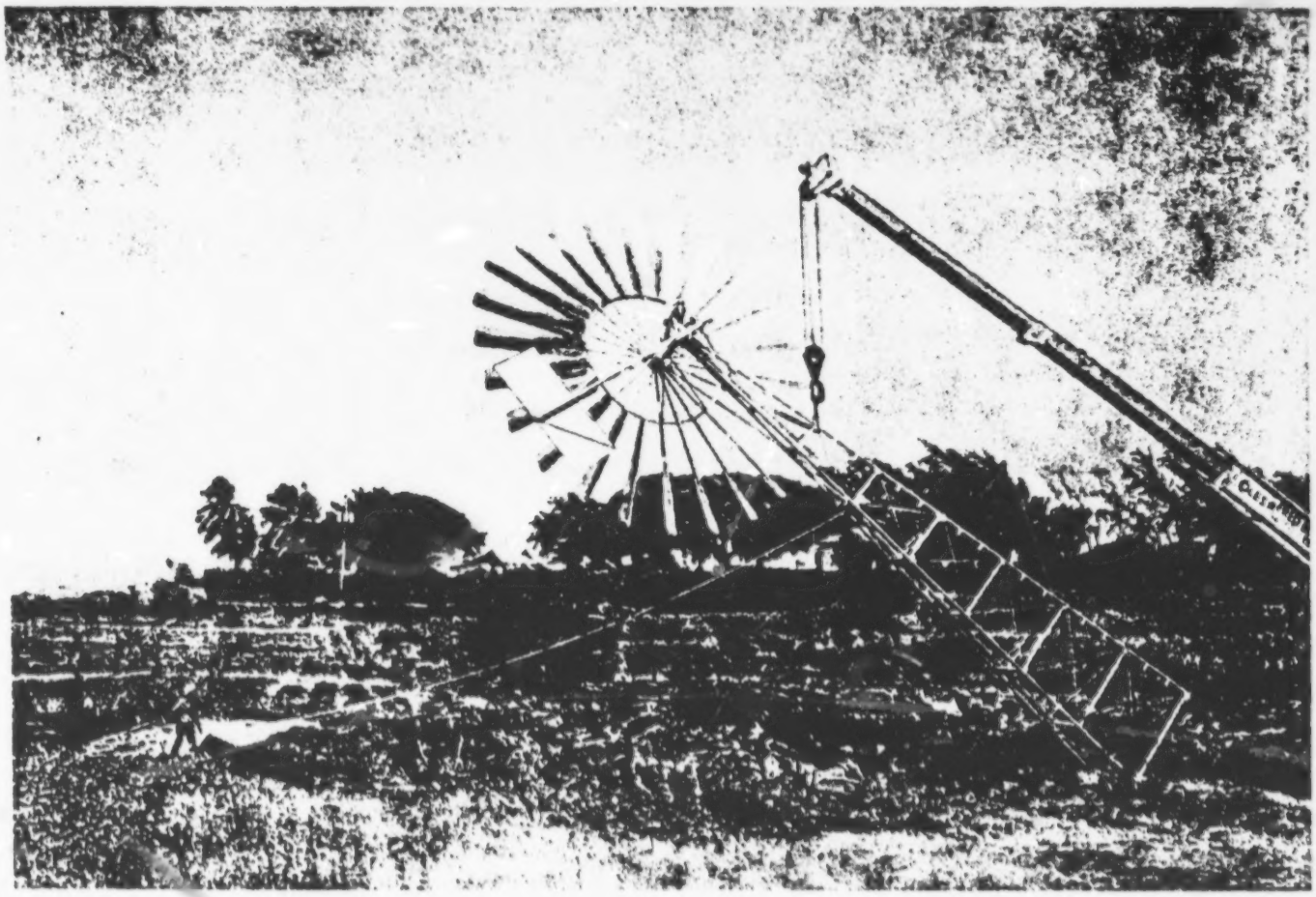

Figure 8.4 Installation of Chinook 7.5 for irrigation pumping demonstration - Barbados Agricultural Development Corp. March, 1987.

will operate reliably for at least 20 years because the electrical utility extension, once installed, is maintained by the utility at no direct cost to the land owner.

For pumping applications in developing countries the options will increasingly be a competition among wind and solar photovoltaics (PV systems) as replacement for conventional diesel pumps. Figure 9.1 illustrates the relative pumping costs of these energy sources. Recent reductions in PV costs may narrow the gap between solar and wind systems, particularly for low volume applications.

10.0 CONSTRAINTS TO WINDPUMP DEVELOPMENTS

An excellent review of current windpumping technology worldwide was commissioned by the World Bank in 1983. One of their most important observations is directly relevant to the state of today's windpump industry:

> "It appears that wind energy technology is undergoing a renaissance, but unfortunately, although our theoretical knowledge is far superior today, our practical experience is limited and there is much risk of mistakes that have been made and corrected a century ago being repeated. There is also a marked tendency for modern wind-power technologists to blind themselves with modern science and to concentrate on esoteric aspects of rotor aerodynamics, at the expense of more mundane but vital engineering details relating to reliability and mechanical or structural integrity".

The report also concludes that "reliability in particular is a vital requirement which can only be achieved through considerable testing under authentic field conditions".

Experience at the Lethbridge test site has repeatedly confirmed the

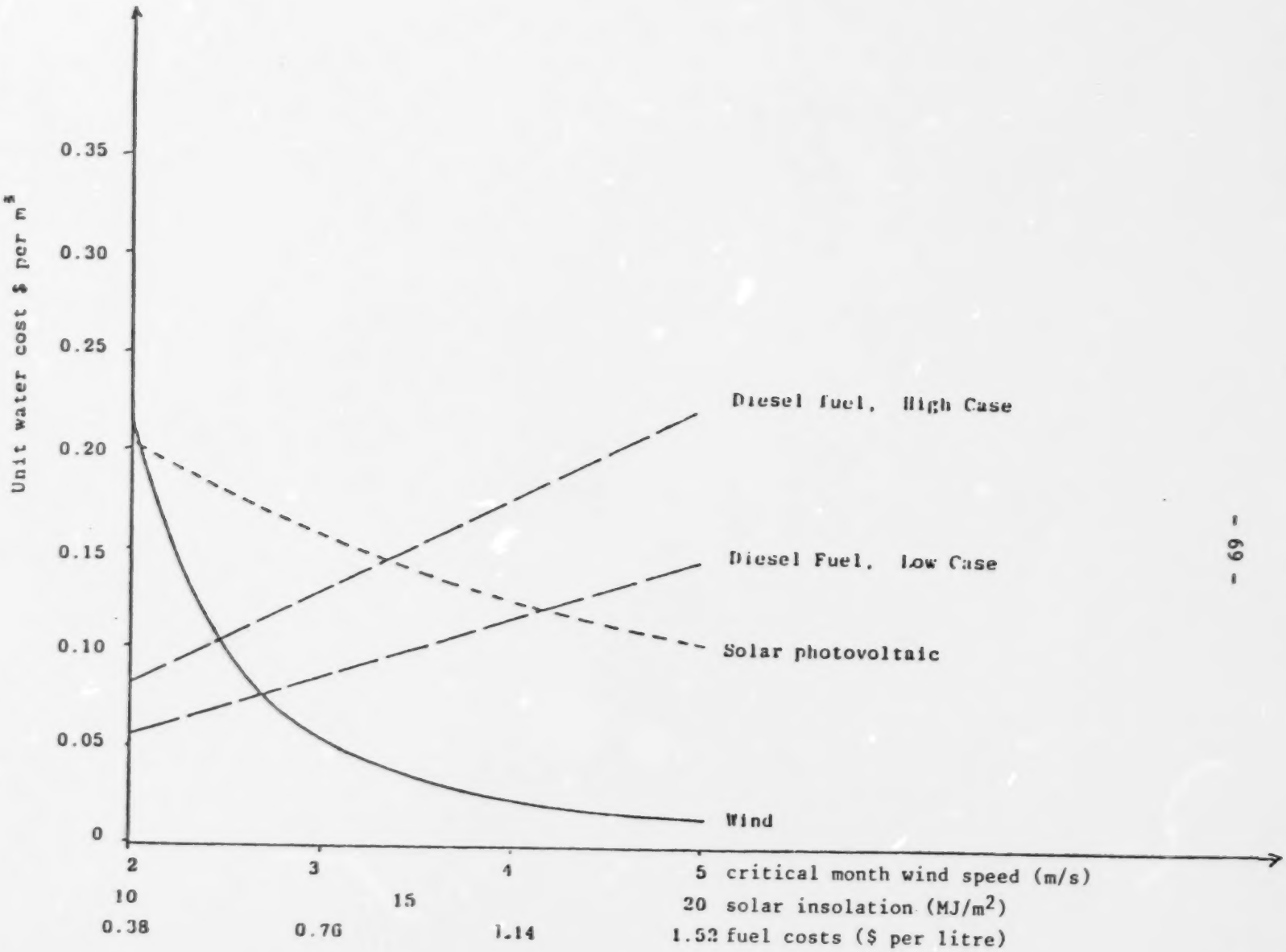

Figure 9.1 Comparison of wind, solar and diesel pumping costs (World Bank, 1983).

need for greater durability in windpump systems. Several new designs have looked very promising for one year but suffered major failures in the second year of their testing program. The benefits of rigorous testing are particularly important for development of the export market potential. This has been well demonstrated by Denmark's success in developing a major export market for electric wind turbines by setting high standards of certification at their test centres. Close cooperation with the industry is also essential to assist in identifying and solving technical problems.

One of the major differences of today's North American windpump market from that of fifty years ago is the lack of customer knowledge about installation, operation and maintenance of windmills and associated pumping equipment. Therefore, successful marketing will require a turn-key approach and continuing service and maintenance which the customer of 1938 may well have undertaken himself.

A complete package approach is even more important in the potential export market to developing countries. There are numerous examples throughout the world of good windpump equipment sitting idle because the original aid program did not provide for adequate training, spare parts and ongoing maintenance. There is a misconception in many quarters that windmills are relatively maintenance free and easy to service. In fact, it requires rather specialized mechanical skills and a good knowledge of pumps and practical plumbing to install and operate a windpump system.

IV

SUMMARY

SUMMARY

11.0 IMPACT OF THE TEST SITE

Public interest in the test site has remained very strong with several hundred visitors per year. Potential purchasers of windpump equipment like the availability of the site for comparison of systems.

11.1 Attracting New Industry

The LWRTS has been a major factor in making Southern Alberta a centre of wind energy development in Canada. In addition to providing a service to existing local manufacturers, the establishment of the Test Centre has attracted several companies from outside Canada which are considering manufacturing windpumps in Southern Alberta, either directly or by license agreement with Alberta firms. The Whirlwind, Wilks and Chinook are all imported mills being considered for local manufacture.

11.2 Export Market Development

It is apparent that the test site could play a major role in assisting Canadian manufacturers to compete in the international market for windpumps. The use of the well simulator will permit equipment testing and certification for a specified pumping application prior to export. Discussions are underway with the Canadian International Development Agency (CIDA) about how to best implement this service.

11.3 Pump Development

Availability of the well simulator has prompted a joint research project between Jensen Engineering Ltd. and the Prairie Agricultural

Machinery Institute (PAMI) in Lethbridge. The objective is to develop and test new pump designs for higher volume pumping. To date tests have been conducted on 150 mm and 300 mm diameter pumps at various strokes. Test results are summarized in Appendix C. Ongoing work is proposed to test larger diameters and other materials for pump construction. This is an excellent use for the simulator during the winter months when the wind test site is not operating. The portability of the simulator makes it easy to transport to the PAMI located at Lethbridge College.

12.0 CONCLUSIONS AND RECOMMENDATIONS

1. The LWRTS continues to generate expanding interest in windpump developments and applications, both in Canada and internationally.
2. The fabrication of the well simulator has greatly enhanced the capabilities of the site and will permit testing of windpumps for a wide range of flows and pressures. This service should be beneficial to manufacturers for system design and refinements, as well as generation of certified performance curves for export equipment.
3. Most windpump equipment tested to date continues to exhibit unacceptably high maintenance requirements. The challenge for manufacturers is to build a windpumping system that will operate 20 years with only annual lubrication and minor maintenance. Most systems have a long way to go to achieve that goal.
4. More attention is needed to the pumps and plumbing components of the windpumping systems. These areas are experiencing more failures than the turbine components.
5. Major markets await the windpump developers who finally produce reliable and affordable products. The test site will help to identify who these winners will be.

13.0 REFERENCES

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APPENDIX "A"

PUMPING SYSTEM SPECIFICATIONS

LETHBRIDGE WIND TURBINE TEST SITE
PERFORMANCE SUMMARY

WINDPUMP NAME & MODEL

WILKS CAM 10

Supplier:

Wind Energy Unlimited Inc.

Address:

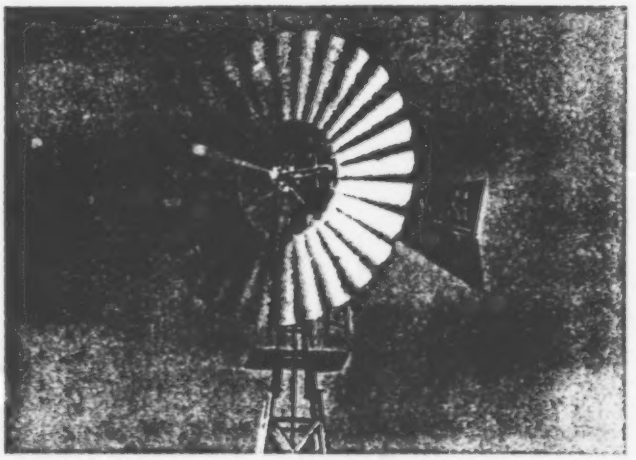
1000 E. William Street

Carson City, Nevada

U.S.A. 89701

Telephone:

(702) 883-9303



SPECIFICATIONS

Turbine Type: Upwind

Axis: Horizontal

Rotor Diameter: 3.05m

Number of Blades: 28

Blade Design: High Torque Sails

Blade Material: Galvanized Steel (16GA)

Hub Height: 12.2m

Generator: N/A

Transmission: Oil Bath

Pumping System Description: Reciprocating rod connected to positive displacement pump

Gear Ratio: 3.77 : 1

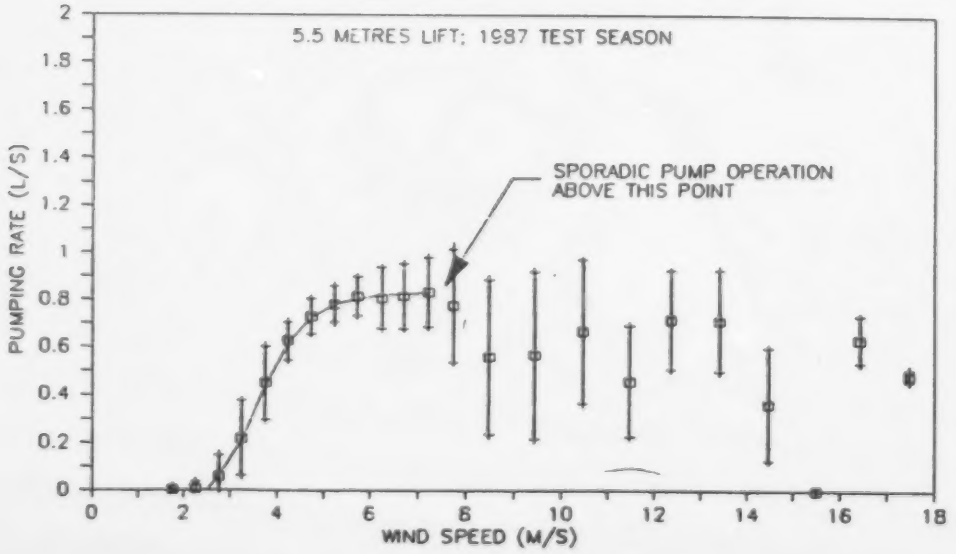
Pump Type: Reciprocating Piston

Pump Size: 127mm

Stroke Range: 178 - 254mm

Stroke Tested: 254mm

TEST RESULTS



LETHBRIDGE WIND TURBINE TEST SITE
PERFORMANCE SUMMARY

WINDPUMP NAME & MODEL

CHINOOK 7.5

Supplier:

Canadian Agtechnology

Partners Inc.

Address:

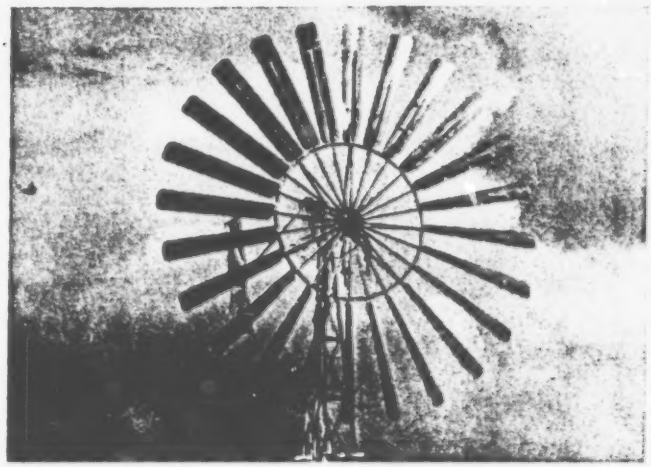
P.O. Box 2457

Olds, Alberta

T0M 1P0

Telephone:

(403) 886-8779



SPECIFICATIONS

Turbine Type: Upwind

Axis: Horizontal

Rotor Diameter: 7.5m

Number of Blades: 24

Blade Design: High Torque

Blade Material: Galvanized Steel

Hub Height: 12.32m

Generator: N/A

Transmission: Direct Drive

Pumping System Description:

Crank drives reciprocating rod connected to positive displacement pump

Gear Ratio: 1:1

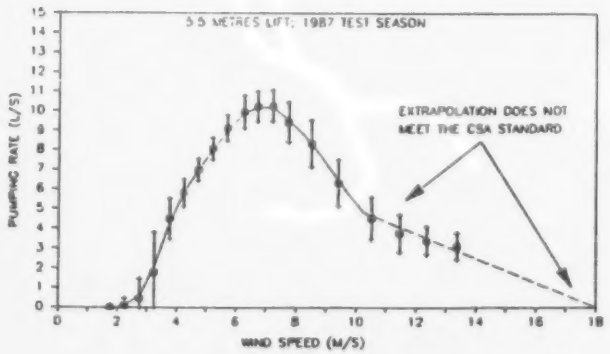
Pump Type: Reciprocating Piston

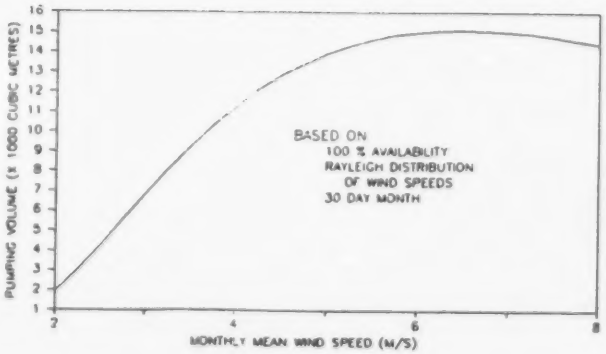
Pump Size: 305mm

Stroke Range: 200mm to 305mm

Stroke Tested: 305mm

TEST RESULTS





LETHBRIDGE WIND TURBINE TEST SITE
PERFORMANCE SUMMARY

WINDPUMP NAME & MODEL

BOWJON

Supplier:

Prairie Ditching Ltd.

Phone: 327-8280

Address:

418 - 26th Street, S.

Lethbridge, Alberta

T1J 3R2

Telephone:

SPECIFICATIONS

Turbine Type: Up wind

Axis: Horizontal

Rotor Diameter: 8 feet (2.44m)

Number of Blades: 6

Blade Design: Triangular Air Foil

Blade Material: Polystyrene

Hub Height: 24 feet (7.32m)

Generator: N/A

Transmission: Direct drive to air compressor

Pumping System Description:

Piston Air Compressor

Gear Ratio: 1:1

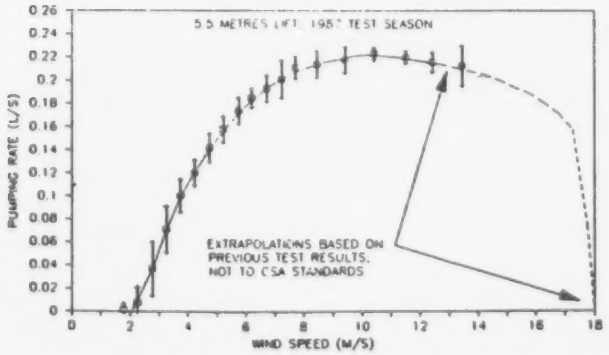
Pump Type: Diaphram

Pump Size: N/A

Stroke Range: N/A

Stroke Tested: N/A

TEST RESULTS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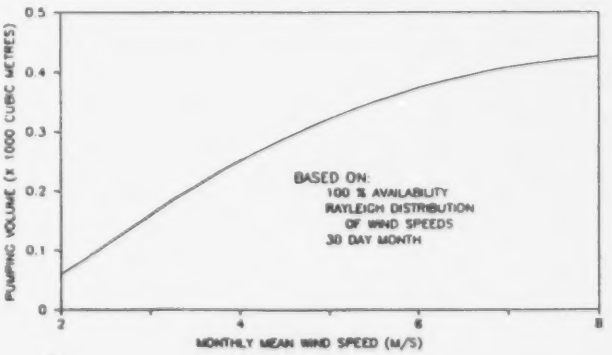
PUMPING RATE (L/S)
WIND SPEED (M/S)
EXTRAPOLATIONS BASED ON PREVIOUS TEST RESULTS, NOT TO CSA STANDARDS


PUMPING VOLUME (X 1000 CUBIC METRES)
MONTHLY MEAN WIND SPEED (M/S)
BASED ON:
100 % AVAILABILITY
RAYLEIGH DISTRIBUTION OF WIND SPEEDS
30 DAY MONTH

LETHBRIDGE WIND TURBINE TEST SITE

PERFORMANCE SUMMARY

WINDPUMP NAME & MODEL

Bowjon Homesteader

Supplier:

Prairie Ditching Ltd.

Address:

418 - 26th Street South

Lethbridge, Alberta

T1J 3R2

Telephone:

(403) 327-8280

Not Exactly as Illustrated

SPECIFICATIONS

Turbine Type: Up wind

Axis: Horizontal

Rotor Diameter: 1.8 meters

Number of Blades: 5

Blade Design: N/A

Blade Material: Stainless Steel

Hub Height: 6.1 metres

Generator: N/A

Transmission: Direct drive to air compressor

Pumping System Description:

Piston Air Compressor

Gear Ratio: 1:1

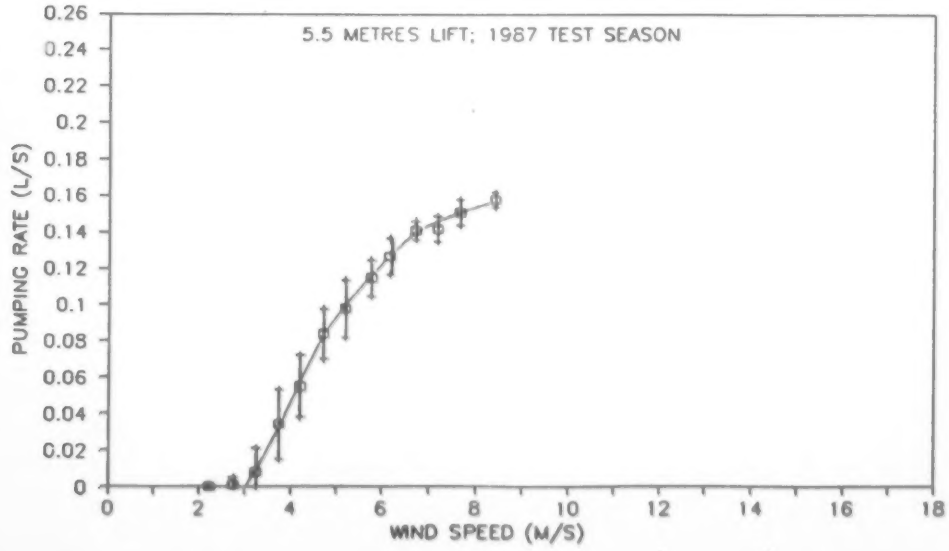
Pump Type: Air lift bubbler

Pump Size: N/A

Stroke Range: N/A

Stroke Tested: N/A

TEST RESULTS



LETHBRIDGE WIND TURBINE TEST SITE
PERFORMANCE SUMMARY

WINDPUMP NAME & MODEL

DELTX WP-20

Supplier:

Deltx Windpump Corporation

Address:

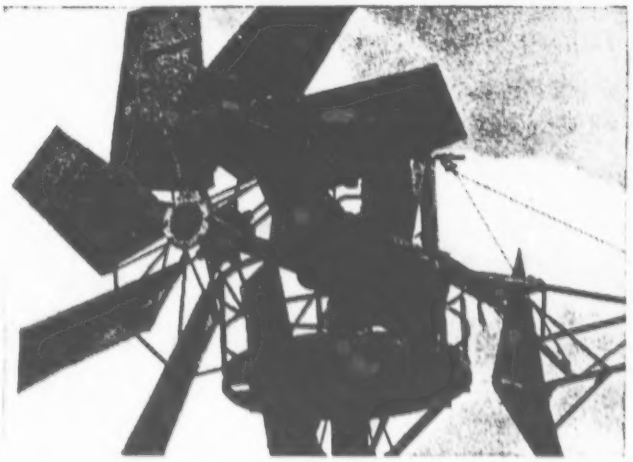
5929 - 6th Street N.E.

Calgary, Alberta

T2K 5R5

Telephone:

(403) 275-6260



SPECIFICATIONS

Turbine Type: Upwind

Axis: Horizontal

Rotor Diameter: 5m

Number of Blades: 8

Blade Design: Delta Wing

Blade Material: Steel

Hub Height: 15.8m

Generator: N/A

Transmission: Hydraulic

Pumping System Description:

Reciprocating Hydraulic Ram

Operates 2 Double-acting Piston Pumps

Gear Ratio: 1 : 1

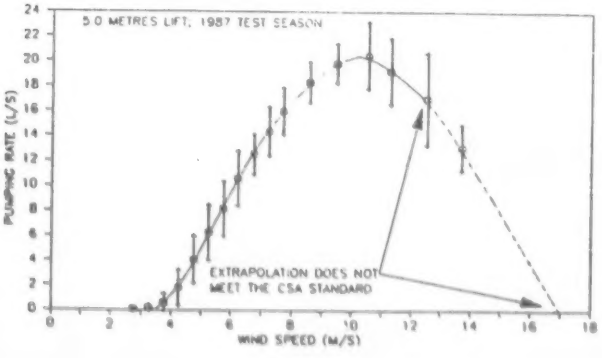
Pump Type: Steel Cylinders

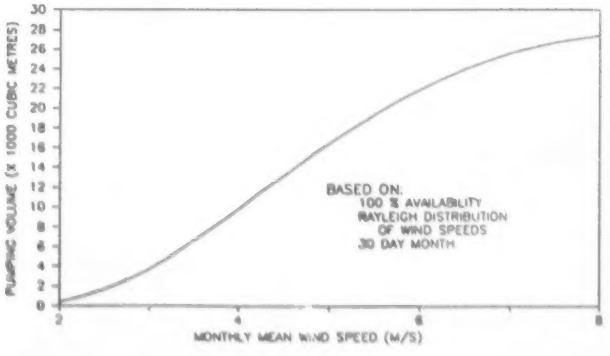
Pump Size: 610mm

Stroke Range: 228mm

Stroke Tested: 228mm

TEST RESULTS




PUMPING VOLUME (X 1000 CUBIC METRES)
MONTHLY MEAN WIND SPEED (M/S)
BASED ON:
100 % AVAILABILITY
RAYLEIGH DISTRIBUTION OF WIND SPEEDS
30 DAY MONTH

LETHBRIDGE WIND TURBINE TEST SITE
PERFORMANCE SUMMARY

WINDPUMP NAME & MODEL

MAESTRO

Supplier:

Nor'Wester Energy Systems Ltd.

Address:

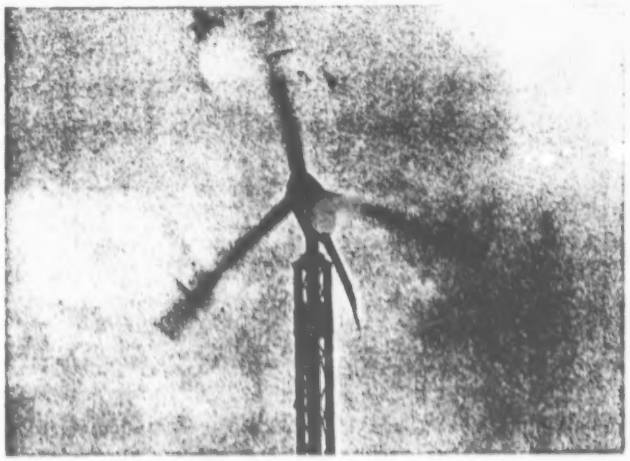
Box 7, Site 32, R.R. #12

Calgary, Alberta

T3E 6W3

Telephone:

(403) 249-3337



SPECIFICATIONS

Turbine Type: Upwind

Axis: Horizontal

Rotor Diameter: 3m

Number of Blades: 3

Blade Design: NACA Highspeed Airfoil

Blade Material: Fibreglass

Hub Height: 18.9m

Generator: BERGEY PM Alternator

Transmission: Direct Drive

Pumping System Description:

Battery storage to Inverter to 110V AC pump

Gear Ratio: N/A

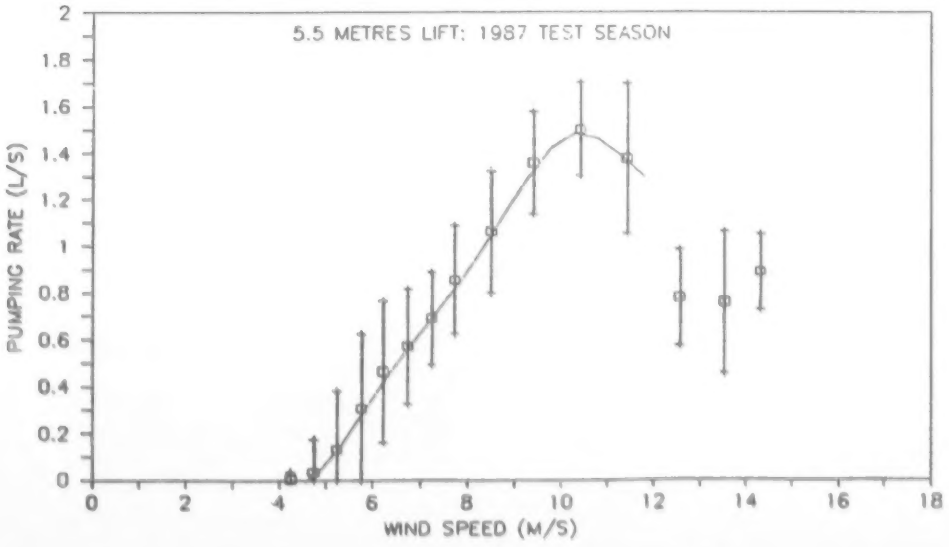
Pump Type: Submersible

Pump Size: 1/2 H.P.

Stroke Range: N/A

Stroke Tested: N/A

TEST RESULTS



LETHBRIDGE WIND TURBINE TEST SITE
PERFORMANCE SUMMARY

WINDPUMP NAME & MODEL

Whirlwind W4

Supplier:

Danecraft Mechanical Design Ltd.

Address:

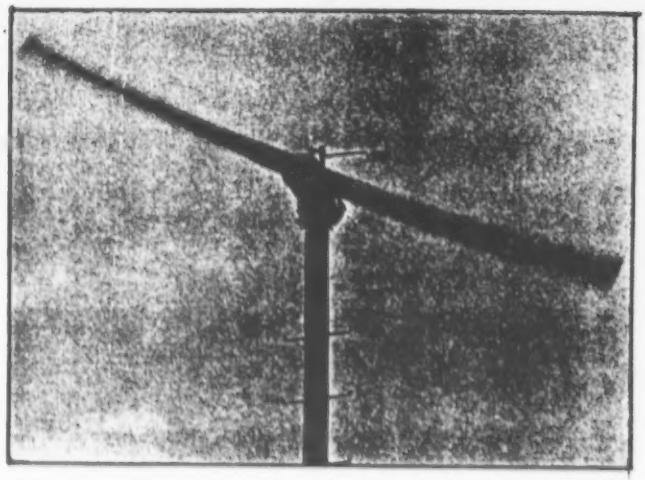
5516D - 40th Street S.E.

Calgary, Alberta

T2C 2A1

Telephone:

(403) 236-9096



SPECIFICATIONS

Turbine Type: Upwind

Axis: Horizontal

Rotor Diameter: 4.88m

Number of Blades: 2

Blade Design: F x 66 Airfoil

Blade Material: Wood (Sitka Spruce)

Hub Height: 12.8m

Generator: 3 Phase P.M. 220V AC

Transmission: Direct Drive

Pumping System Description:

Generator to Logic Control to Electric Pump

Gear Ratio: Generator : Motor 1:9

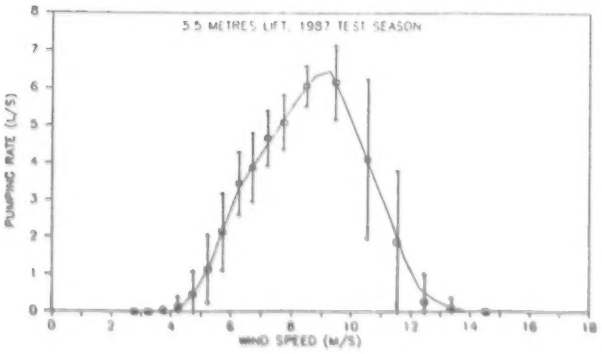
Pump Type: Centrifugal 3 Phase 3500 RPM

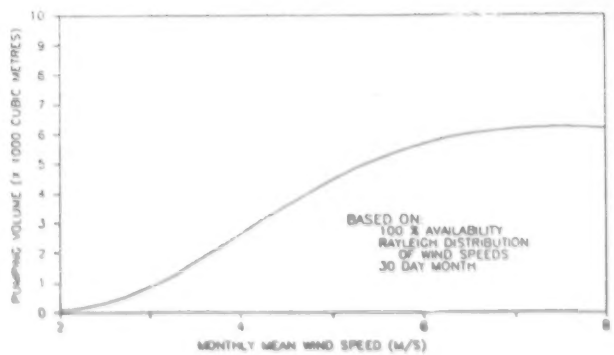
Pump Size: 3 H.P.

Stroke Range: N/A

Stroke Tested: N/A

TEST RESULTS





LETHBRIDGE WIND TURBINE TEST SITE

PERFORMANCE SUMMARY

WINDPUMP NAME & MODEL

MAVERICK WINDMOTOR

Supplier:

Maverick Wind Energy

Address:

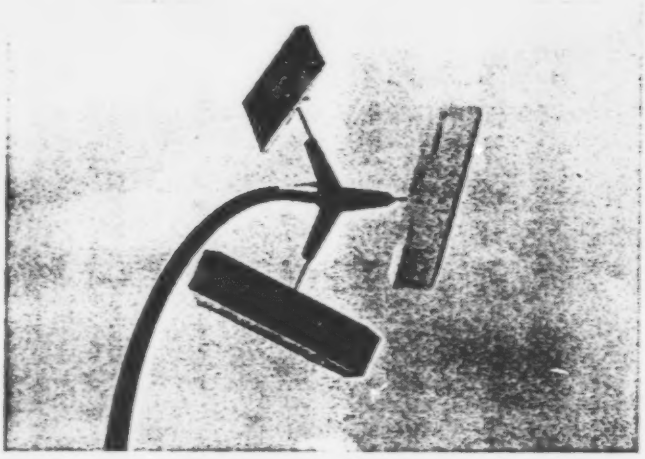
P.O. Box 2707

Pincher Creek, Alberta

T0K 1W0

Telephone:

(403)627-3630



SPECIFICATIONS

Turbine Type: Downwind

Axis: Horizontal

Rotor Diameter: 2.44m

Number of Blades: 2

Blade Design:

Blade Material: Extruded Aluminum

Hub Height: 7.62m

Generator: N/A

Transmission: Direct Drive

Pumping System Description:

Direct cable drive from rotor to pump

Gear Ratio: 1:1

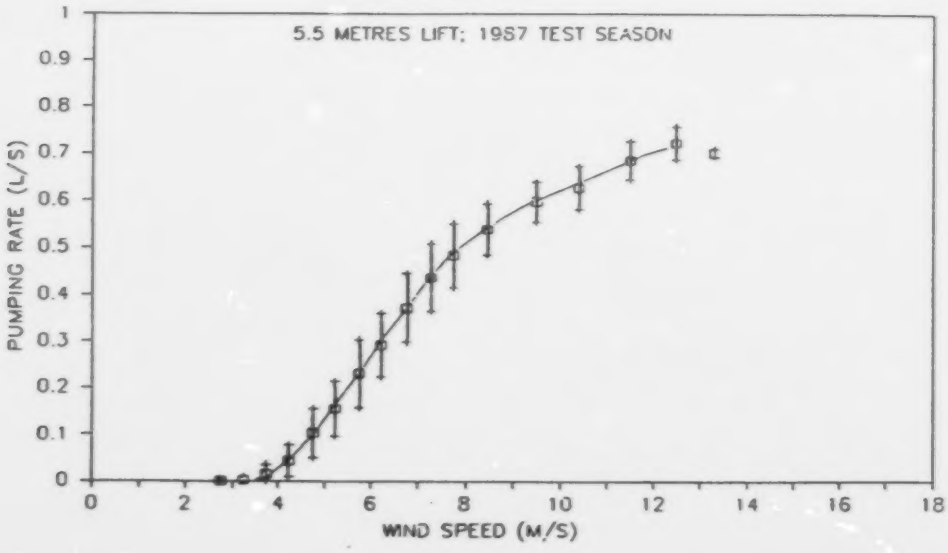
Pump Type: Helical progressing cavity

Pump Size: 51mm

Stroke Range: N/A

Stroke Tested: N/A

TEST RESULTS



MANUFACTURER'S SPECIFICATIONS

DATE: April 02, 1987
CONTACT: Jim Fox

NAME OF MACHINE: ENVIRONMENTAL SYSTEMS

MANUFACTURER: PUMP BY MacDONALD PANEL BY ARCO

DISTRIBUTOR: ENVIRONMENTAL SYSTEMS CANADA LIMITED
Box 370
INGERSOL, ONTARIO N5C 3V3 (519)485-0290

SYSTEM DESCRIPTION

PANEL TYPE: ARCO

PUMP TYPE: SINGLE STAGE CENTRIFUGAL PUMP

Number of Panels: 4

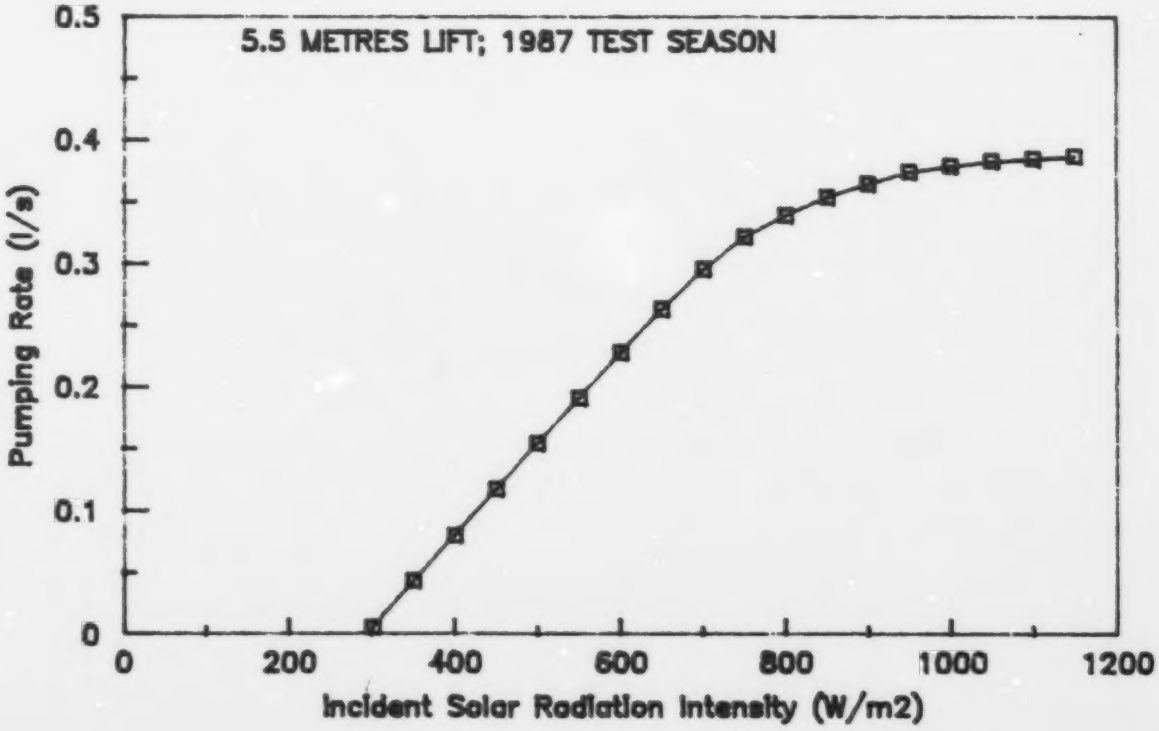
Panel Wiring Scheme: CONNECTED IN PARALLEL

Total Panel Output: 172 WATTS

Pump Motor Rated Output: 250 Watts (1/3 h.p.)

Outlet Size: 32mm

TEST RESULTS:



MANUFACTURER'S SPECIFICATIONS

DATE: March 31, 1987
CONTACT: Stuart Middleton

NAME OF MACHINE: CAMPRO PORTABLE

MANUFACTURER: PUMP BY JACUZZI ---- PANEL BY ARCO

DISTRIBUTOR: CAMBRIAN ENGINEERING GROUP LIMITED
519 - 105th Street East
Saskatoon, Saskatchewan S7N 1Z2

SYSTEM DESCRIPTION

PANEL TYPE: ARCO

PUMP TYPE: SUBMERSIBLE MULTISTAGE CENTRIFUGAL (4 stages)

Number of Panels: 6

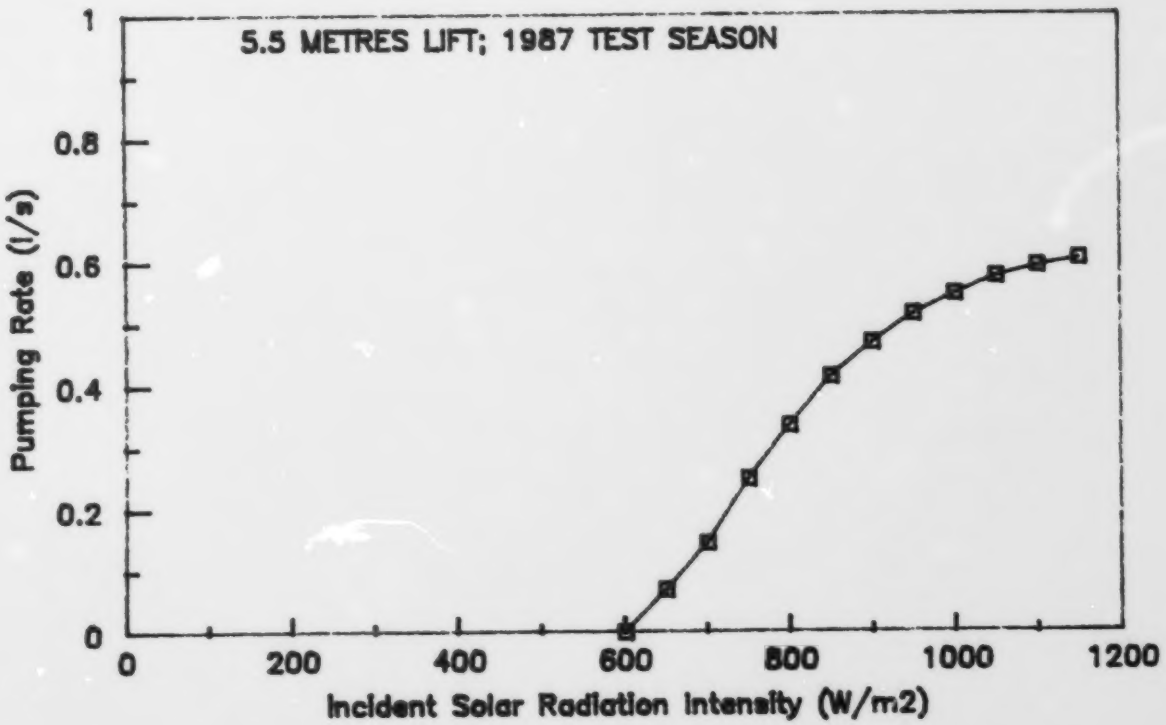
Panel Wiring Scheme: 3 series 2 parallel

Total Panel Output: 250 watts

Pump Motor Rated Output: 250 watts (1/3 h.p.)

Outlet Size: 38mm

TEST RESULTS:



APPENDIX "B"

PERFORMANCE DATA AND RAW DATA PLOTS

METHOD OF BINS RESULT FOR: WILKS CAM 10
PUMPING AGAINST A 5.5 METRE HEAD

BIN NO. I	BIN INTERVAL M/S	NUMBER OF REDUCED DATA SETS N	B I N AIR DENSITY KG/M^3	S A M P L E A V E R A G E WIND SPEED M/S	TURBULENCE INTENSITY PERCENT	ROTOR SPEED RPM	FLOW RATE L/S	BIN SAMPLE STANDARD DEVIATION WIND SPEED M/S	TURBULENCE INTENSITY PERCENT	ROTOR SPEED RPM	FLOW RATE L/S	MEET CSA MDBR REQUIREMENTS ROTOR SPEED	FLOW RATE
1	1.5 TO 2.0	627	1.105	1.76	21.18	0.2	0.002	0.14	12.54	1.0	0.012	Y	Y
2	2.0 TO 2.5	772	1.106	2.24	16.63	0.9	0.008	0.14	10.34	2.2	0.027	Y	Y
3	2.5 TO 3.0	689	1.107	2.75	14.26	4.6	0.057	0.14	8.77	6.7	0.090	Y	Y
4	3.0 TO 3.5	758	1.107	3.23	12.58	16.2	0.218	0.15	7.47	11.1	0.157	Y	Y
5	3.5 TO 4.0	622	1.105	3.75	11.94	31.5	0.449	0.14	6.23	10.2	0.154	Y	Y
6	4.0 TO 4.5	542	1.100	4.23	12.10	44.0	0.626	0.14	5.90	4.8	0.081	Y	Y
7	4.5 TO 5.0	500	1.097	4.73	11.27	53.3	0.730	0.14	5.89	4.9	0.074	Y	Y
8	5.0 TO 5.5	408	1.092	5.23	12.10	61.6	0.781	0.15	4.89	4.6	0.077	Y	Y
9	5.5 TO 6.0	287	1.096	5.72	12.33	70.2	0.815	0.14	4.47	4.3	0.082	Y	Y
10	6.0 TO 6.5	189	1.095	6.24	14.10	77.8	0.808	0.14	3.57	4.7	0.130	Y	Y
11	6.5 TO 7.0	127	1.091	6.70	14.54	83.0	0.817	0.14	7.05	5.3	0.138	Y	Y
12	7.0 TO 7.5	90	1.095	7.22	13.67	88.1	0.833	0.15	2.63	6.0	0.149	Y	Y
13	7.5 TO 8.0	45	1.092	7.74	14.65	95.4	0.776	0.15	4.01	4.8	0.239	Y	N
14	8.0 TO 9.0	116	1.089	8.49	14.11	104.2	0.560	0.30	2.96	5.4	0.326	Y	N
15	9.0 TO 10.0	65	1.082	9.44	15.03	108.1	0.567	0.30	2.39	3.9	0.353	Y	N
16	10.0 TO 11.0	39	1.085	10.47	14.64	107.0	0.668	0.27	3.81	5.2	0.305	Y	N
17	11.0 TO 12.0	22	1.078	11.47	14.57	101.9	0.460	0.31	1.73	5.2	0.232	Y	N
18	12.0 TO 13.0	19	1.082	12.36	14.30	89.5	0.718	0.28	1.64	10.6	0.208	Y	N
19	13.0 TO 14.0	13	1.079	13.41	13.77	82.0	0.714	0.24	2.09	6.1	0.214	Y	N
20	14.0 TO 15.0	6	1.084	14.46	15.02	44.3	0.362	0.28	2.23	21.3	0.235	N	N
21	15.0 TO 16.0	-	-	-	-	-	-	-	-	-	-	-	-
22	16.0 TO 17.0	5	1.076	16.43	12.56	43.4	0.636	0.56	0.55	7.3	0.099	N	N
23	17.0 TO 18.0	2	1.077	17.47	12.09	32.1	0.485	0.33	0.28	1.0	0.025	N	N

TOTAL NUMBER OF
REDUCED DATA SETS: 6548
AVERAGE TEMPERATURE
DURING THE TEST: 288.0 DEGREES KELVIN
AVERAGE PRESSURE
DURING THE TEST: 91.04 KPA

METHOD OF BINS RESULT FOR: CHINOOK 7.5
PUMPING AGAINST A 5.5 METRE HEAD

BIN NO. I	BIN INTERVAL M/S	NUMBER OF REDUCED DATA SETS N	BIN AIR DENSITY KG/M^3	SAMPLE AVERAGE WIND SPEED M/S	SAMPLE AVERAGE TURBULENCE INTENSITY PERCENT	SAMPLE AVERAGE ROTOR SPEED RPM	SAMPLE AVERAGE FLOW RATE L/S	BIN SAMPLE STANDARD DEVIATION WIND SPEED M/S	BIN SAMPLE STANDARD DEVIATION TURBULENCE INTENSITY PERCENT	BIN SAMPLE STANDARD DEVIATION ROTOR SPEED RPM	BIN SAMPLE STANDARD DEVIATION FLOW RATE L/S	MEET CSA MDBR REQUIREMENTS ROTOR SPEED	MEET CSA MDBR REQUIREMENTS FLOW RATE
1	1.5 TO 2.0	388	1.108	1.76	21.90	0.1	0.034	0.14	12.46	0.2	0.110	Y	Y
2	2.0 TO 2.5	542	1.108	2.24	16.50	0.3	0.117	0.14	10.46	0.8	0.353	Y	Y
3	2.5 TO 3.0	452	1.110	2.75	13.20	1.2	0.565	0.14	8.06	2.2	0.998	Y	Y
4	3.0 TO 3.5	529	1.110	3.23	11.22	4.9	2.220	0.15	6.56	4.4	2.023	Y	Y
5	3.5 TO 4.0	422	1.107	3.76	10.80	12.3	5.633	0.14	8.51	2.2	1.014	Y	Y
6	4.0 TO 4.5	396	1.103	4.23	9.72	15.9	7.265	0.13	4.74	1.5	0.687	Y	Y
7	4.5 TO 5.0	362	1.099	4.72	9.03	19.1	8.732	0.14	5.20	1.1	0.540	Y	Y
8	5.0 TO 5.5	182	1.092	5.20	9.79	22.0	10.066	0.15	4.70	1.1	0.556	Y	Y
9	5.5 TO 6.0	75	1.094	5.70	12.11	24.7	11.400	0.13	4.86	1.4	0.670	Y	Y
10	6.0 TO 6.5	46	1.082	6.27	14.05	27.0	12.446	0.14	3.92	1.7	0.836	Y	Y
11	6.5 TO 7.0	46	1.071	6.72	13.45	27.9	12.806	0.14	2.21	1.6	0.770	Y	Y
12	7.0 TO 7.5	47	1.083	7.22	13.03	28.0	12.834	0.14	2.05	1.7	0.797	Y	Y
13	7.5 TO 8.0	35	1.081	7.74	13.68	25.7	11.789	0.16	2.89	2.2	1.027	Y	Y
14	8.0 TO 9.0	109	1.080	8.50	13.91	22.7	10.430	0.29	2.67	2.5	1.190	Y	Y
15	9.0 TO 10.0	68	1.076	9.41	14.53	17.2	7.892	0.30	2.27	2.6	1.182	Y	Y
16	10.0 TO 11.0	37	1.076	10.51	14.72	12.4	5.657	0.25	3.78	2.3	1.053	Y	Y
17	11.0 TO 12.0	22	1.077	11.45	14.74	10.3	4.693	0.30	1.92	2.0	0.943	N	N
18	12.0 TO 13.0	16	1.082	12.35	14.16	9.3	4.244	0.30	1.52	1.5	0.689	N	N
19	13.0 TO 14.0	7	1.081	13.36	14.01	8.5	3.886	0.24	1.79	1.4	0.659	N	N
20	14.0 TO 15.0	-	-	-	-	-	-	-	-	-	-	-	-
21	15.0 TO 16.0	-	-	-	-	-	-	-	-	-	-	-	-
22	16.0 TO 17.0	-	-	-	-	-	-	-	-	-	-	-	-
23	17.0 TO 18.0	-	-	-	-	-	-	-	-	-	-	-	-

TOTAL NUMBER OF
REDUCED DATA SETS: 3782
AVERAGE TEMPERATURE
DURING THE TEST: 288.0 DEGREES KELVIN
AVERAGE PRESSURE
DURING THE TEST: 91.11 KPA

METHOD OF BINS RESULT FOR: BOWJON DIAPHRAGM
PUMPING AGAINST A 5.5 METRE HEAD

BIN NO. I	BIN INTERVAL M/S	NUMBER OF REDUCED DATA SETS N	BIN SAMPLE AVERAGE AIR DENSITY KG/M^3	BIN SAMPLE AVERAGE WIND SPEED M/S	BIN SAMPLE AVERAGE TURBULENCE INTENSITY PERCENT	BIN SAMPLE AVERAGE FLOW RATE L/S	BIN SAMPLE STANDARD DEVIATION WIND SPEED M/S	BIN SAMPLE STANDARD DEVIATION TURBULENCE INTENSITY PERCENT	BIN SAMPLE STANDARD DEVIATION FLOW RATE L/S	MEET CSA MDBR REQUIREMENTS FLOW RATE
1	1.5 TO 2.0	377	1.106	1.77	19.47	0.002	0.14	12.40	0.005	Y
2	2.0 TO 2.5	422	1.108	2.24	15.23	0.008	0.14	9.80	0.013	Y
3	2.5 TO 3.0	432	1.107	2.75	12.50	0.037	0.15	7.41	0.023	Y
4	3.0 TO 3.5	380	1.103	3.24	11.63	0.071	0.14	6.38	0.020	Y
5	3.5 TO 4.0	350	1.096	3.74	12.02	0.100	0.15	5.94	0.014	Y
6	4.0 TO 4.5	322	1.093	4.22	11.49	0.120	0.14	5.41	0.011	Y
7	4.5 TO 5.0	229	1.085	4.74	12.45	0.142	0.14	5.17	0.012	Y
8	5.0 TO 5.5	132	1.082	5.21	13.65	0.158	0.15	4.68	0.011	Y
9	5.5 TO 6.0	81	1.080	5.75	14.65	0.174	0.13	3.08	0.011	Y
10	6.0 TO 6.5	77	1.073	6.20	14.50	0.185	0.14	2.39	0.008	Y
11	6.5 TO 7.0	42	1.078	6.73	13.80	0.193	0.14	1.97	0.011	Y
12	7.0 TO 7.5	25	1.071	7.25	15.08	0.201	0.13	4.01	0.016	Y
13	7.5 TO 8.0	38	1.083	7.73	15.11	0.211	0.13	2.54	0.009	Y
14	8.0 TO 9.0	63	1.077	8.47	14.70	0.214	0.27	2.03	0.011	Y
15	9.0 TO 10.0	42	1.087	9.43	14.93	0.218	0.29	1.67	0.011	Y
16	10.0 TO 11.0	24	1.080	10.42	14.81	0.223	0.29	2.08	0.005	Y
17	11.0 TO 12.0	23	1.080	11.51	14.97	0.220	0.27	1.38	0.005	Y
18	12.0 TO 13.0	17	1.084	12.43	14.98	0.216	0.16	2.53	0.008	Y
19	13.0 TO 14.0	3	1.083	13.44	12.69	0.213	0.30	1.05	0.017	N
20	14.0 TO 15.0	-	-	-	-	-	-	-	-	-
21	15.0 TO 16.0	-	-	-	-	-	-	-	-	-
22	16.0 TO 17.0	-	-	-	-	-	-	-	-	-
23	17.0 TO 18.0	-	-	-	-	-	-	-	-	-

TOTAL NUMBER OF
REDUCED DATA SETS: 3079
AVERAGE TEMPERATURE
DURING THE TEST: 289.1 DEGREES KELVIN
AVERAGE PRESSURE
DURING THE TEST: 91.00 KPA

METHOD OF BINS RESULT FOR: BOWJON AIR LIFT
PUMPING AGAINST A 5.5 METRE HEAD

BIN NO. I	BIN INTERVAL M/S	NUMBER OF REDUCED DATA SETS N	BIN SAMPLE AVERAGE AIR DENSITY KG/M^3	BIN SAMPLE AVERAGE WIND SPEED M/S	BIN SAMPLE AVERAGE TURBULENCE INTENSITY PERCENT	BIN SAMPLE AVERAGE FLOW RATE L/S	BIN SAMPLE STANDARD DEVIATION WIND SPEED M/S	BIN SAMPLE STANDARD DEVIATION TURBULENCE INTENSITY PERCENT	BIN SAMPLE STANDARD DEVIATION FLOW RATE L/S	MEET CSA MDBR REQUIREMENTS FLOW RATE
2	2.0 TO 2.5	105	1.104	2.22	16.00	0.000	0.13	10.26	0.001	Y
3	2.5 TO 3.0	90	1.104	2.74	13.79	0.001	0.15	6.80	0.004	Y
4	3.0 TO 3.5	99	1.099	3.24	11.80	0.008	0.15	5.28	0.013	Y
5	3.5 TO 4.0	124	1.094	3.74	11.67	0.034	0.14	5.42	0.019	Y
6	4.0 TO 4.5	99	1.087	4.21	10.89	0.055	0.15	4.74	0.017	Y
7	4.5 TO 5.0	51	1.082	4.72	13.24	0.084	0.13	4.52	0.014	Y
8	5.0 TO 5.5	32	1.083	5.19	16.73	0.098	0.16	3.70	0.016	Y
9	5.5 TO 6.0	17	1.057	5.76	15.79	0.115	0.12	2.29	0.010	Y
10	6.0 TO 6.5	26	1.054	6.16	16.19	0.127	0.12	2.11	0.010	Y
11	6.5 TO 7.0	11	1.056	6.72	13.73	0.141	0.14	2.25	0.005	Y
12	7.0 TO 7.5	5	1.045	7.18	16.37	0.142	0.09	2.34	0.007	N
13	7.5 TO 8.0	10	1.063	7.66	15.22	0.151	0.11	1.54	0.007	Y
14	8.0 TO 9.0	9	1.065	8.41	13.75	0.158	0.28	1.58	0.004	N
15	9.0 TO 10.0	-	-	-	-	-	-	-	-	-
16	10.0 TO 11.0	-	-	-	-	-	-	-	-	-
17	11.0 TO 12.0	-	-	-	-	-	-	-	-	-
18	12.0 TO 13.0	-	-	-	-	-	-	-	-	-
19	13.0 TO 14.0	-	-	-	-	-	-	-	-	-
20	14.0 TO 15.0	-	-	-	-	-	-	-	-	-
21	15.0 TO 16.0	-	-	-	-	-	-	-	-	-
22	16.0 TO 17.0	-	-	-	-	-	-	-	-	-
23	17.0 TO 18.0	-	-	-	-	-	-	-	-	-

TOTAL NUMBER OF
REDUCED DATA SETS: 679
AVERAGE TEMPERATURE
DURING THE TEST: 291.4 DEGREES KELVIN
AVERAGE PRESSURE
DURING THE TEST: 91.19 KPA

METHOD OF BINS RESULT FOR: DELTX WP-20
PUMPING AGAINST A 5.0 METRE HEAD

BIN NO.	BIN INTERVAL M/S	NUMBER OF REDUCED DATA SETS	BIN SAMPLE AVERAGE					BIN SAMPLE STANDARD DEVIATION				MEET CSA MDBR REQUIREMENTS	
			AIR DENSITY	WIND SPEED	TURBULENCE INTENSITY	ROTOR SPEED	FLOW RATE	WIND SPEED	TURBULENCE INTENSITY	ROTOR SPEED	FLOW RATE	ROTOR	FLOW
I		N	KG/M^3	M/S	PERCENT	RPM	L/S	M/S	PERCENT	RPM	L/S	SPEED	RATE
3	2.5 TO 3.0	180	1.107	2.75	14.55	0.8	0.089	0.14	8.49	0.5	0.128	Y	Y
4	3.0 TO 3.5	218	1.108	3.26	12.39	0.8	0.192	0.14	6.42	0.5	0.240	Y	Y
5	3.5 TO 4.0	229	1.111	3.76	11.50	1.4	0.638	0.14	6.34	1.0	0.695	Y	Y
6	4.0 TO 4.5	235	1.103	4.25	11.73	2.8	1.842	0.14	5.63	1.6	1.443	Y	Y
7	4.5 TO 5.0	239	1.098	4.76	11.28	5.1	4.097	0.15	6.25	1.9	1.884	Y	Y
8	5.0 TO 5.5	242	1.094	5.24	11.13	7.2	6.268	0.15	5.23	2.1	2.176	Y	Y
9	5.5 TO 6.0	160	1.093	5.73	11.71	9.0	8.182	0.14	4.63	2.1	2.177	Y	Y
10	6.0 TO 6.5	95	1.090	6.22	12.81	11.2	10.606	0.16	4.47	2.1	2.167	Y	Y
11	6.5 TO 7.0	78	1.085	6.74	14.56	13.0	12.560	0.13	3.06	1.5	1.590	Y	Y
12	7.0 TO 7.5	37	1.082	7.25	13.73	14.8	14.386	0.13	3.70	1.8	1.934	Y	Y
13	7.5 TO 8.0	32	1.083	7.71	13.05	16.5	16.002	0.14	3.04	1.8	1.852	Y	Y
14	8.0 TO 9.0	69	1.085	8.57	14.95	18.7	18.319	0.25	6.80	1.7	1.618	Y	Y
15	9.0 TO 10.0	56	1.078	9.48	13.98	20.3	19.837	0.28	2.57	1.7	1.580	Y	Y
16	10.0 TO 11.0	39	1.087	10.53	14.15	21.0	20.501	0.28	2.21	2.7	2.687	Y	Y
17	11.0 TO 12.0	22	1.082	11.28	15.03	19.6	19.219	0.26	4.82	2.6	2.670	Y	Y
18	12.0 TO 13.0	18	1.085	12.52	14.46	17.5	16.989	0.28	1.91	3.7	3.703	N	N
19	13.0 TO 14.0	10	1.080	13.69	12.88	13.7	13.118	0.27	1.80	1.8	1.827	N	N
20	14.0 TO 15.0	2	1.079	14.64	13.57	23.3	22.495	0.16	2.52	1.9	1.825	N	N
21	15.0 TO 16.0	-	-	-	-	-	-	-	-	-	-	-	-
22	16.0 TO 17.0	-	-	-	-	-	-	-	-	-	-	-	-
23	17.0 TO 18.0	-	-	-	-	-	-	-	-	-	-	-	-

TOTAL NUMBER OF
REDUCED DATA SETS: 1961
AVERAGE TEMPERATURE
DURING THE TEST: 289.0 DEGREES KELVIN
AVERAGE PRESSURE
DURING THE TEST: 91.03 KPA

METHOD OF BINS RESULT FOR: MAESTRO
PUMPING AGAINST A 5.5 METRE HEAD

BIN NO. I	BIN INTERVAL M/S	NUMBER OF REDUCED DATA SETS N	BIN SAMPLE AVERAGE AIR DENSITY KG/M^3	BIN SAMPLE AVERAGE WIND SPEED M/S	BIN SAMPLE AVERAGE TURBULENCE INTENSITY PERCENT	BIN SAMPLE AVERAGE FLOW RATE L/S	BIN SAMPLE STANDARD DEVIATION WIND SPEED M/S	BIN SAMPLE STANDARD DEVIATION TURBULENCE INTENSITY PERCENT	BIN SAMPLE STANDARD DEVIATION FLOW RATE L/S	MEET CSA MDBR REQUIREMENTS FLOW RATE
5	3.5 TO 4.0	474	1.111	3.74	10.13	0.000	0.15	5.59	0.000	Y
6	4.0 TO 4.5	467	1.107	4.24	10.19	0.003	0.14	5.19	0.032	Y
7	4.5 TO 5.0	361	1.104	4.73	9.90	0.033	0.15	5.09	0.141	Y
8	5.0 TO 5.5	351	1.099	5.23	9.87	0.130	0.15	4.74	0.249	Y
9	5.5 TO 6.0	211	1.094	5.75	10.41	0.306	0.14	4.16	0.315	Y
10	6.0 TO 6.5	162	1.095	6.22	11.02	0.462	0.15	4.08	0.300	N
11	6.5 TO 7.0	123	1.096	6.73	12.46	0.570	0.14	2.94	0.244	N
12	7.0 TO 7.5	81	1.099	7.24	13.10	0.690	0.14	2.67	0.198	Y
13	7.5 TO 8.0	68	1.101	7.73	13.14	0.853	0.15	3.50	0.231	Y
14	8.0 TO 9.0	110	1.096	8.50	13.66	1.062	0.30	2.86	0.262	Y
15	9.0 TO 10.0	91	1.091	9.40	13.54	1.360	0.25	2.14	0.219	Y
16	10.0 TO 11.0	47	1.098	10.41	14.02	1.503	0.26	1.99	0.199	Y
17	11.0 TO 12.0	27	1.089	11.42	13.55	1.377	0.29	2.03	0.322	N
18	12.0 TO 13.0	19	1.086	12.56	14.54	0.779	0.24	1.68	0.205	N
19	13.0 TO 14.0	17	1.085	13.53	14.00	0.758	0.31	2.83	0.303	N
20	14.0 TO 15.0	5	1.093	14.31	14.22	0.888	0.34	2.57	0.163	N
21	15.0 TO 16.0	-	-	-	-	-	-	-	-	-
22	16.0 TO 17.0	-	-	-	-	-	-	-	-	-
23	17.0 TO 18.0	-	-	-	-	-	-	-	-	-

TOTAL NUMBER OF
REDUCED DATA SETS: 4768
AVERAGE TEMPERATURE
DURING THE TEST: 287.8 DEGREES KELVIN
AVERAGE PRESSURE
DURING THE TEST: 91.07 KPA

METHOD OF BINS RESULT FOR: WHIRLWIND W4
PUMPING AGAINST A 5.5 METRE HEAD

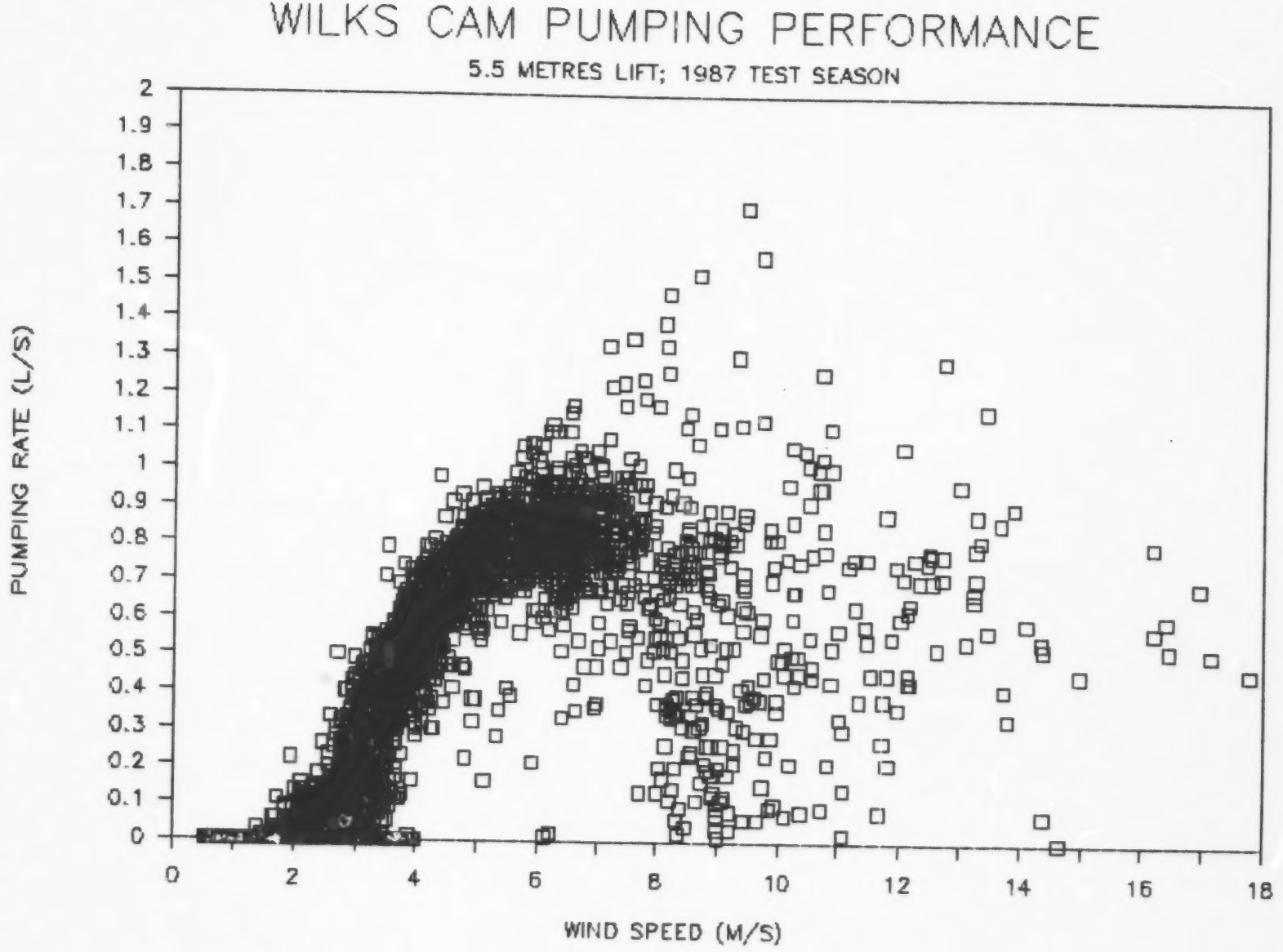
BIN NO. I	BIN INTERVAL M/S	NUMBER OF REDUCED DATA SETS N	BIN SAMPLE AVERAGE AIR DENSITY KG/M^3	BIN SAMPLE AVERAGE WIND SPEED M/S	BIN SAMPLE AVERAGE TURBULENCE INTENSITY PERCENT	BIN SAMPLE AVERAGE FLOW RATE L/S	BIN SAMPLE STANDARD DEVIATION WIND SPEED M/S	BIN SAMPLE STANDARD DEVIATION TURBULENCE INTENSITY PERCENT	BIN SAMPLE STANDARD DEVIATION FLOW RATE L/S	MEET CSA MDBR REQUIREMENTS FLOW RATE
3	2.5 TO 3.0	464	1.105	2.76	14.53	0.001	0.14	9.44	0.013	Y
4	3.0 TO 3.5	534	1.106	3.23	12.53	0.003	0.15	7.82	0.031	Y
5	3.5 TO 4.0	450	1.104	3.74	11.80	0.023	0.14	6.81	0.092	Y
6	4.0 TO 4.5	365	1.097	4.23	12.05	0.141	0.14	6.07	0.253	Y
7	4.5 TO 5.0	335	1.093	4.73	10.88	0.474	0.14	5.62	0.594	Y
8	5.0 TO 5.5	257	1.089	5.23	11.31	1.132	0.15	5.03	0.895	Y
9	5.5 TO 6.0	142	1.092	5.71	11.40	2.136	0.14	4.67	1.024	N
10	6.0 TO 6.5	86	1.091	6.26	14.19	3.435	0.15	3.31	0.834	Y
11	6.5 TO 7.0	55	1.087	6.71	15.79	3.863	0.15	10.13	0.915	Y
12	7.0 TO 7.5	48	1.091	7.21	13.76	4.656	0.13	2.51	0.736	Y
13	7.5 TO 8.0	27	1.090	7.73	14.72	5.087	0.16	4.15	0.724	Y
14	8.0 TO 9.0	69	1.088	8.48	14.43	6.062	0.31	3.28	0.529	Y
15	9.0 TO 10.0	58	1.082	9.46	14.74	6.152	0.30	2.51	0.978	Y
16	10.0 TO 11.0	52	1.078	10.53	14.35	4.097	0.24	3.43	2.136	N
17	11.0 TO 12.0	16	1.082	11.53	14.91	1.861	0.29	1.74	1.913	N
18	12.0 TO 13.0	28	1.085	12.45	14.40	0.271	0.33	2.33	0.734	N
19	13.0 TO 14.0	21	1.081	13.35	13.65	0.104	0.22	1.89	0.265	N
20	14.0 TO 15.0	13	1.075	14.52	14.17	0.000	0.28	1.88	0.000	Y
21	15.0 TO 16.0	14	1.070	15.58	14.99	0.087	0.34	3.16	0.314	N
22	16.0 TO 17.0	17	1.072	16.37	13.50	0.000	0.28	1.38	0.000	Y
23	17.0 TO 18.0	4	1.075	17.40	11.88	0.000	0.26	0.30	0.000	Y

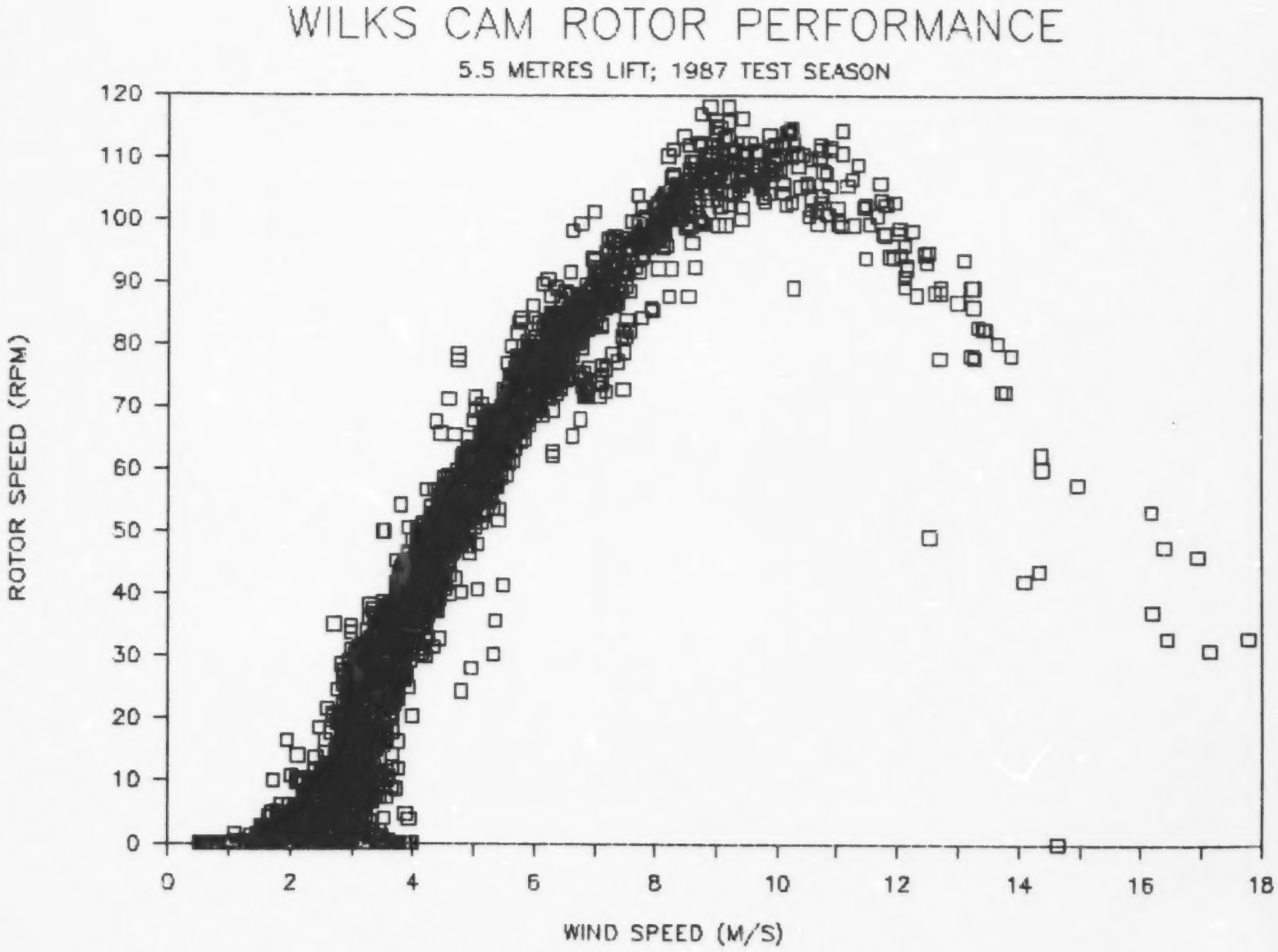
TOTAL NUMBER OF
REDUCED DATA SETS: 3055
AVERAGE TEMPERATURE
DURING THE TEST: 288.7 DEGREES KELVIN
AVERAGE PRESSURE
DURING THE TEST: 90.88 KPA

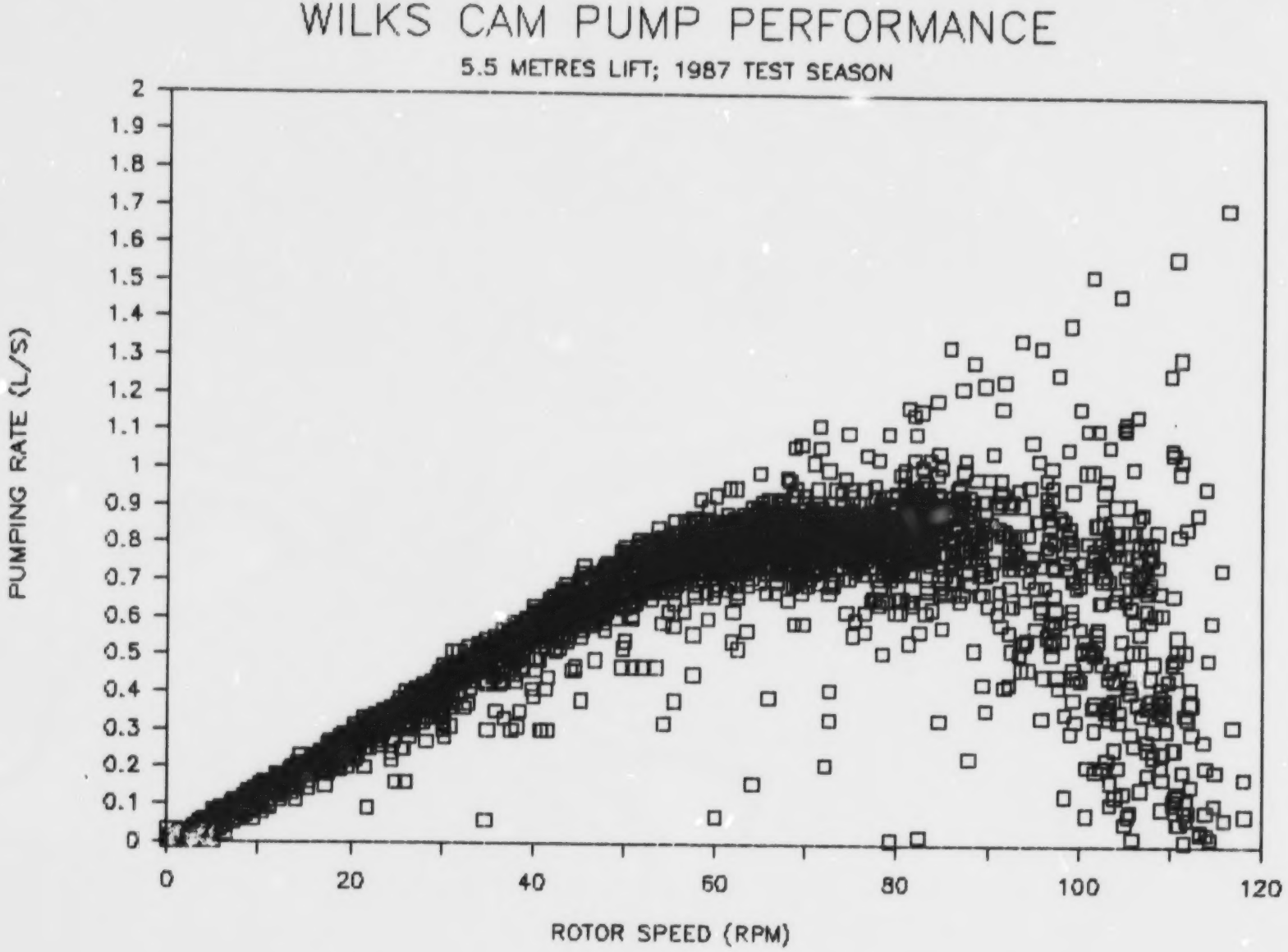
METHOD OF BINS RESULT FOR: WINDMOTOR
PUMPING AGAINST A 5.5 METRE HEAD

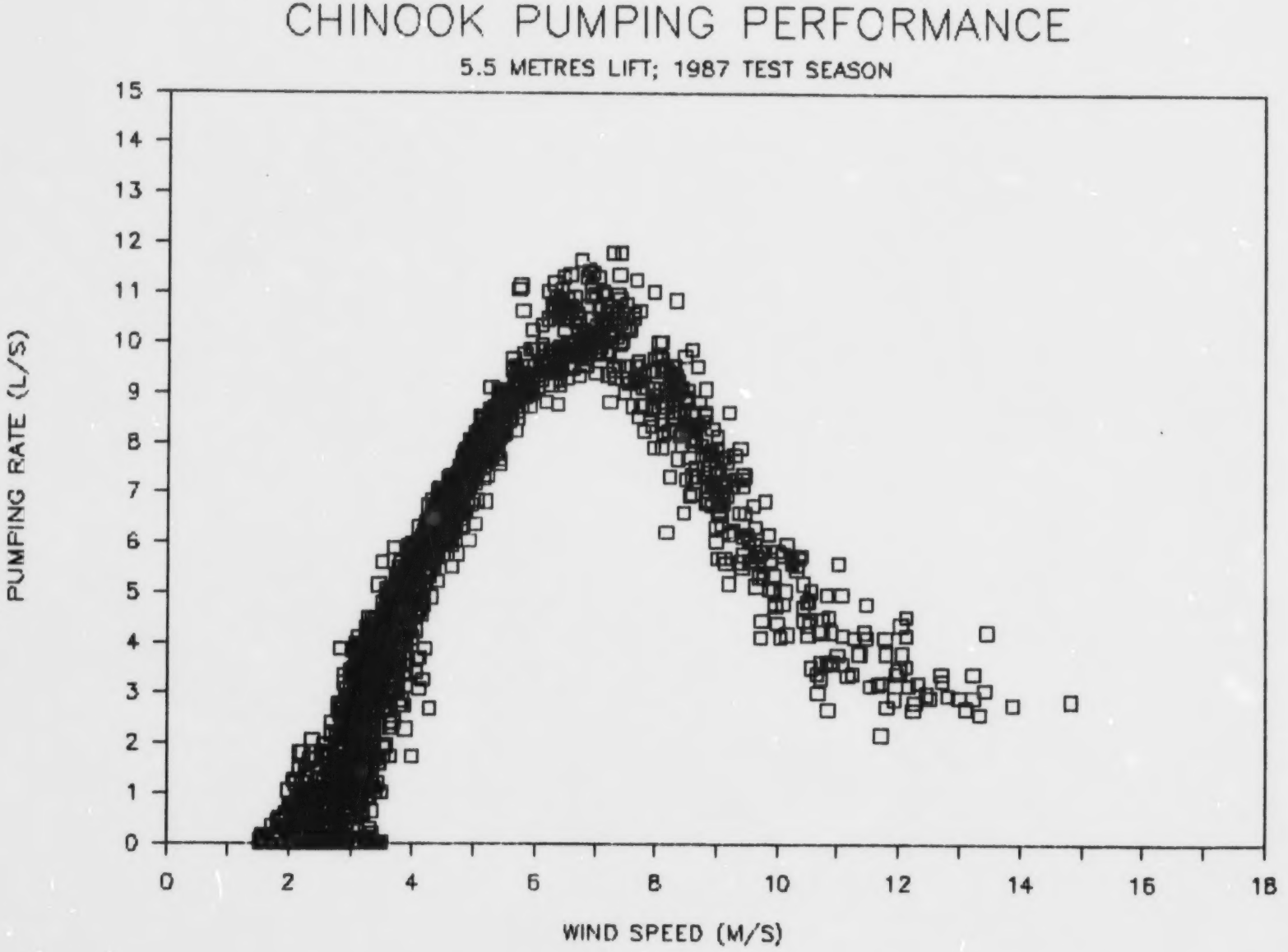
BIN NO. I	BIN INTERVAL M/S	NUMBER OF REDUCED DATA SETS N	BIN SAMPLE AVERAGE AIR DENSITY KG/M^3	WIND SPEED M/S	TURBULENCE INTENSITY PERCENT	ROTOR SPEED RPM	FLOW RATE L/S	BIN SAMPLE STANDARD DEVIATION WIND SPEED M/S	TURBULENCE INTENSITY PERCENT	ROTOR SPEED RPM	FLOW RATE L/S	MEET CSA MDBR REQUIREMENTS ROTOR SPEED	FLOW RATE
1	1.5 TO 2.0	478	1.101	1.77	18.76	0.5	0.000	0.13	12.68	1.8	0.000	Y	Y
2	2.0 TO 2.5	479	1.105	2.24	15.54	2.2	0.000	0.15	9.87	4.9	0.001	Y	Y
3	2.5 TO 3.0	490	1.109	2.74	14.83	9.9	0.000	0.14	8.16	12.2	0.002	Y	Y
4	3.0 TO 3.5	413	1.109	3.24	13.93	26.9	0.002	0.15	6.55	16.8	0.006	Y	Y
5	3.5 TO 4.0	348	1.106	3.74	15.10	46.2	0.014	0.15	5.70	18.6	0.021	Y	Y
6	4.0 TO 4.5	296	1.104	4.22	15.67	63.7	0.042	0.15	5.03	15.8	0.034	Y	Y
7	4.5 TO 5.0	249	1.097	4.75	15.67	83.7	0.102	0.15	5.14	16.7	0.052	Y	Y
8	5.0 TO 5.5	217	1.100	5.22	15.35	100.6	0.154	0.14	3.52	15.3	0.058	Y	Y
9	5.5 TO 6.0	177	1.101	5.74	15.12	123.0	0.229	0.14	3.16	18.7	0.073	Y	Y
10	6.0 TO 6.5	129	1.094	6.21	15.26	140.3	0.291	0.15	3.24	19.3	0.069	Y	Y
11	6.5 TO 7.0	71	1.094	6.75	14.65	164.6	0.371	0.14	2.95	21.9	0.074	Y	Y
12	7.0 TO 7.5	52	1.094	7.26	15.28	185.9	0.436	0.15	3.1[illegible]	20.9	0.072	Y	Y
13	7.5 TO 8.0	67	1.088	7.73	15.63	199.4	0.483	0.14	3.53	20.7	0.068	Y	Y
14	8.0 TO 9.0	98	1.083	8.43	15.03	217.5	0.539	0.29	2.42	16.1	0.055	Y	Y
15	9.0 TO 10.0	52	1.087	9.48	15.79	236.5	0.597	0.31	3.54	13.3	0.042	Y	Y
16	10.0 TO 11.0	27	1.081	10.37	15.35	246.1	0.627	0.35	2.16	14.5	0.045	Y	Y
17	11.0 TO 12.0	14	1.088	11.48	15.16	261.4	0.684	0.21	1.80	12.1	0.040	N	Y
18	12.0 TO 13.0	11	1.079	12.46	13.72	273.1	0.721	0.20	1.62	8.7	0.035	Y	Y
19	13.0 TO 14.0	2	1.077	13.28	17.23	270.7	0.700	0.09	0.42	6.5	0.010	N	N
20	14.0 TO 15.0	-	-	-	-	-	-	-	-	-	-	-	-
21	15.0 TO 16.0	-	-	-	-	-	-	-	-	-	-	-	-
22	16.0 TO 17.0	-	-	-	-	-	-	-	-	-	-	-	-
23	17.0 TO 18.0	-	-	-	-	-	-	-	-	-	-	-	-

TOTAL NUMBER OF
REDUCED DATA SETS: 3670
AVERAGE TEMPERATURE
DURING THE TEST: 288.0 DEGREES KELVIN
AVERAGE PRESSURE
DURING THE TEST: 91.07 KPA


WILKS CAM PUMPING PERFORMANCE
5.5 METRES LIFT; 1987 TEST SEASON
PUMPING RATE (L/S)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
16
18
WIND SPEED (M/S)

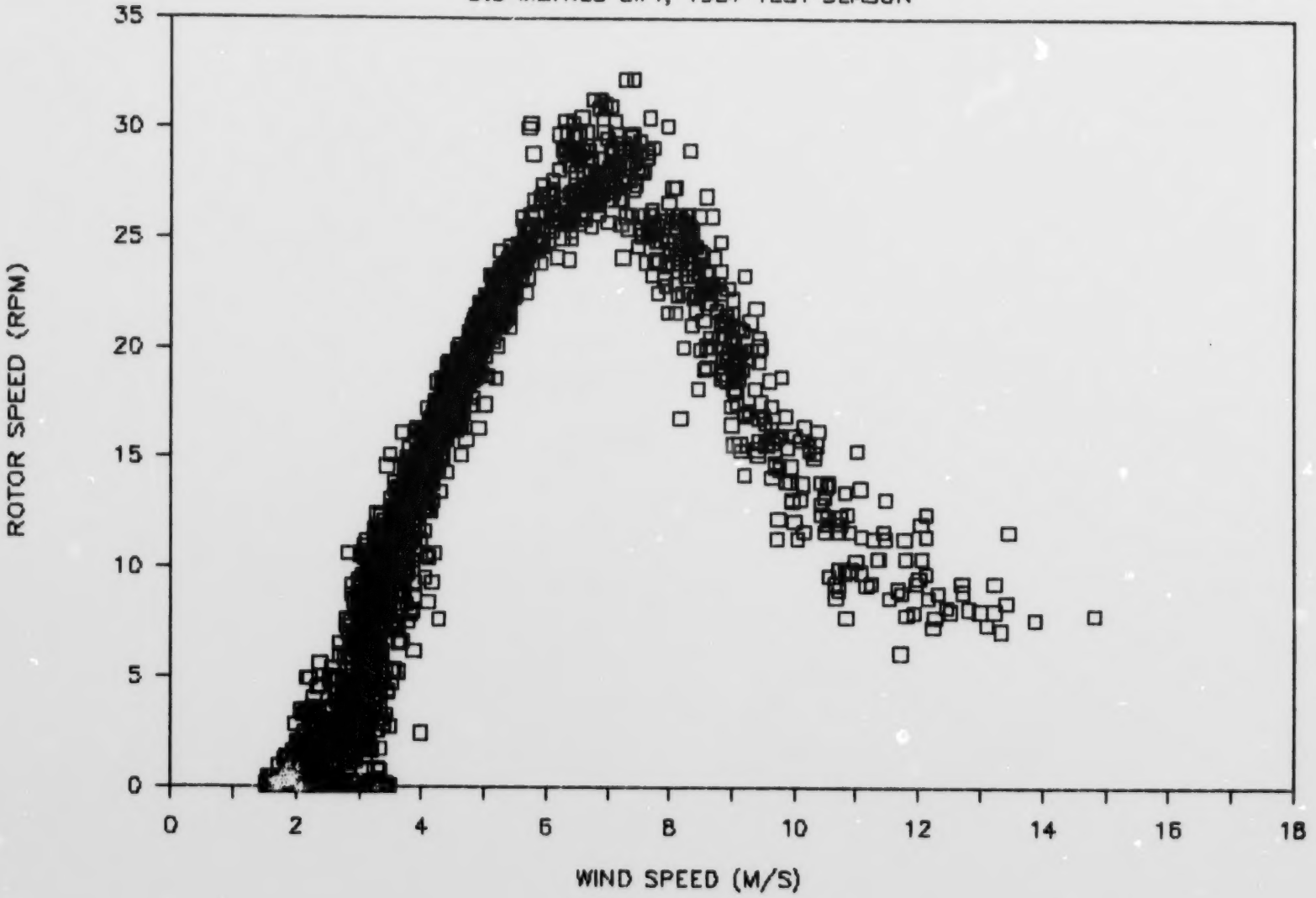

WILKS CAM ROTOR PERFORMANCE
5.5 METRES LIFT; 1987 TEST SEASON
ROTOR SPEED (RPM)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
WIND SPEED (M/S)

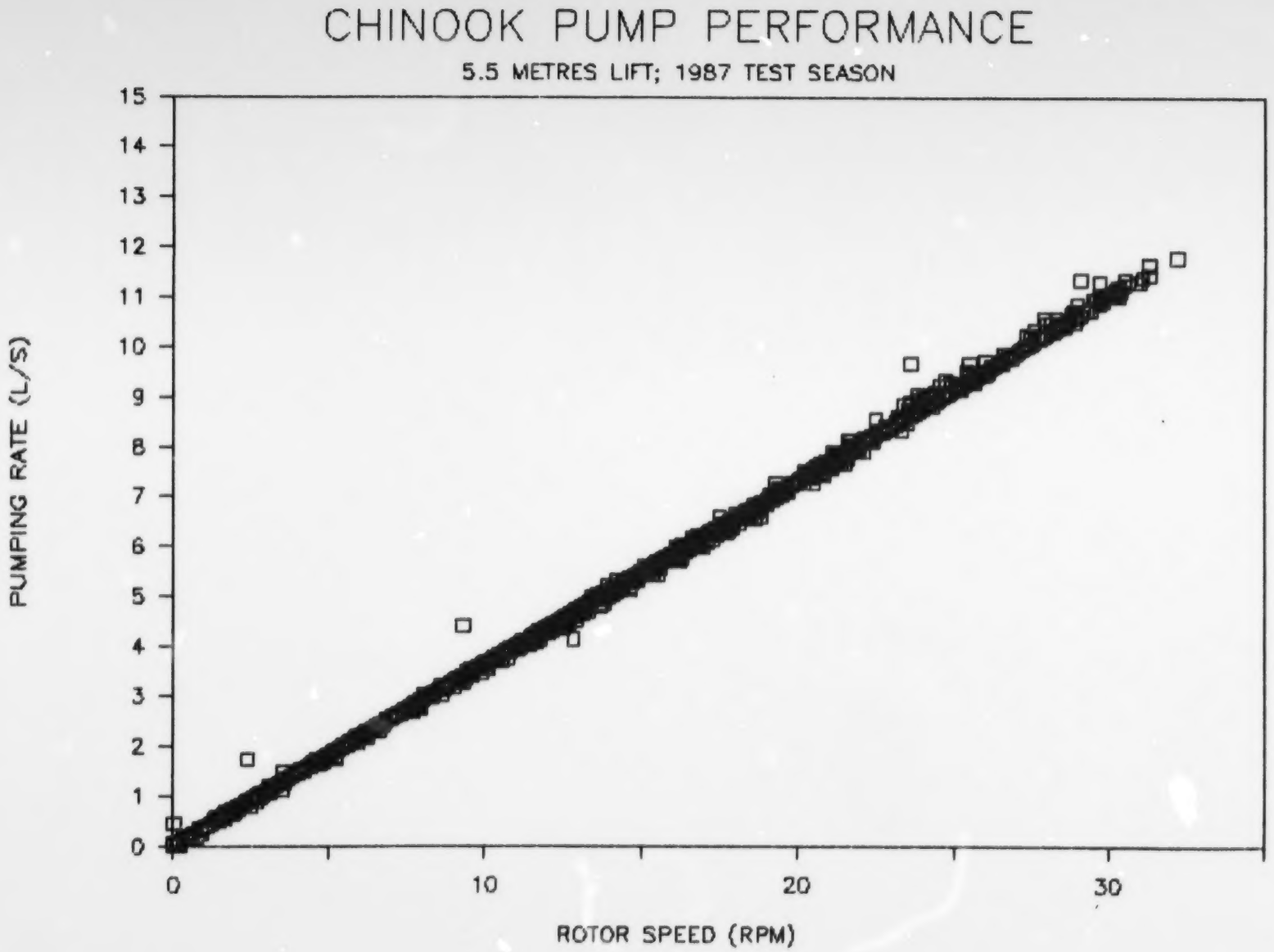

WILKS CAM PUMP PERFORMANCE
5.5 METRES LIFT; 1987 TEST SEASON
PUMPING RATE (L/S)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
ROTOR SPEED (RPM)

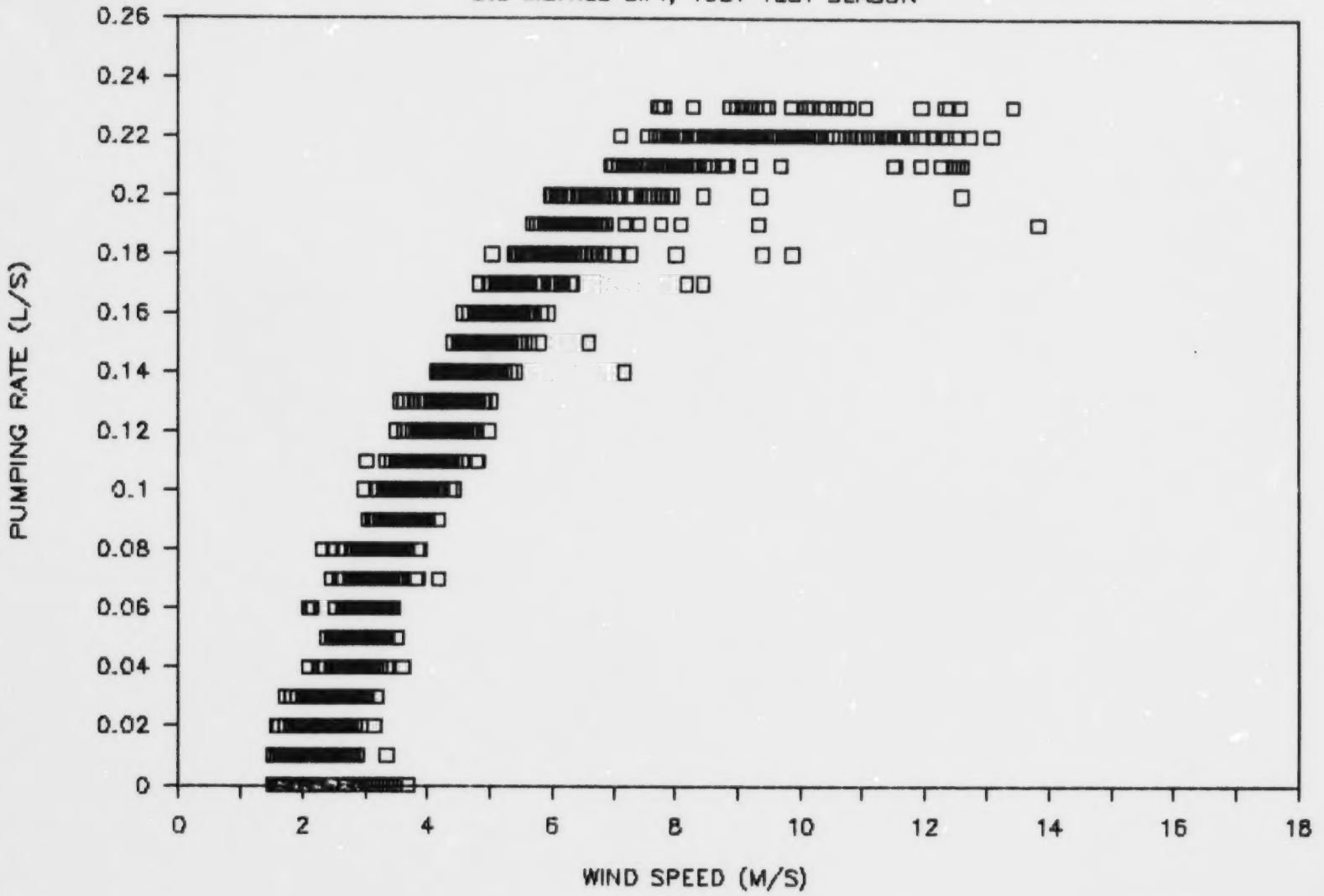

CHINOOK PUMPING PERFORMANCE
5.5 METRES LIFT; 1987 TEST SEASON
PUMPING RATE (L/S)
WIND SPEED (M/S)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0
2
4
6
8
10
12
14
16
18

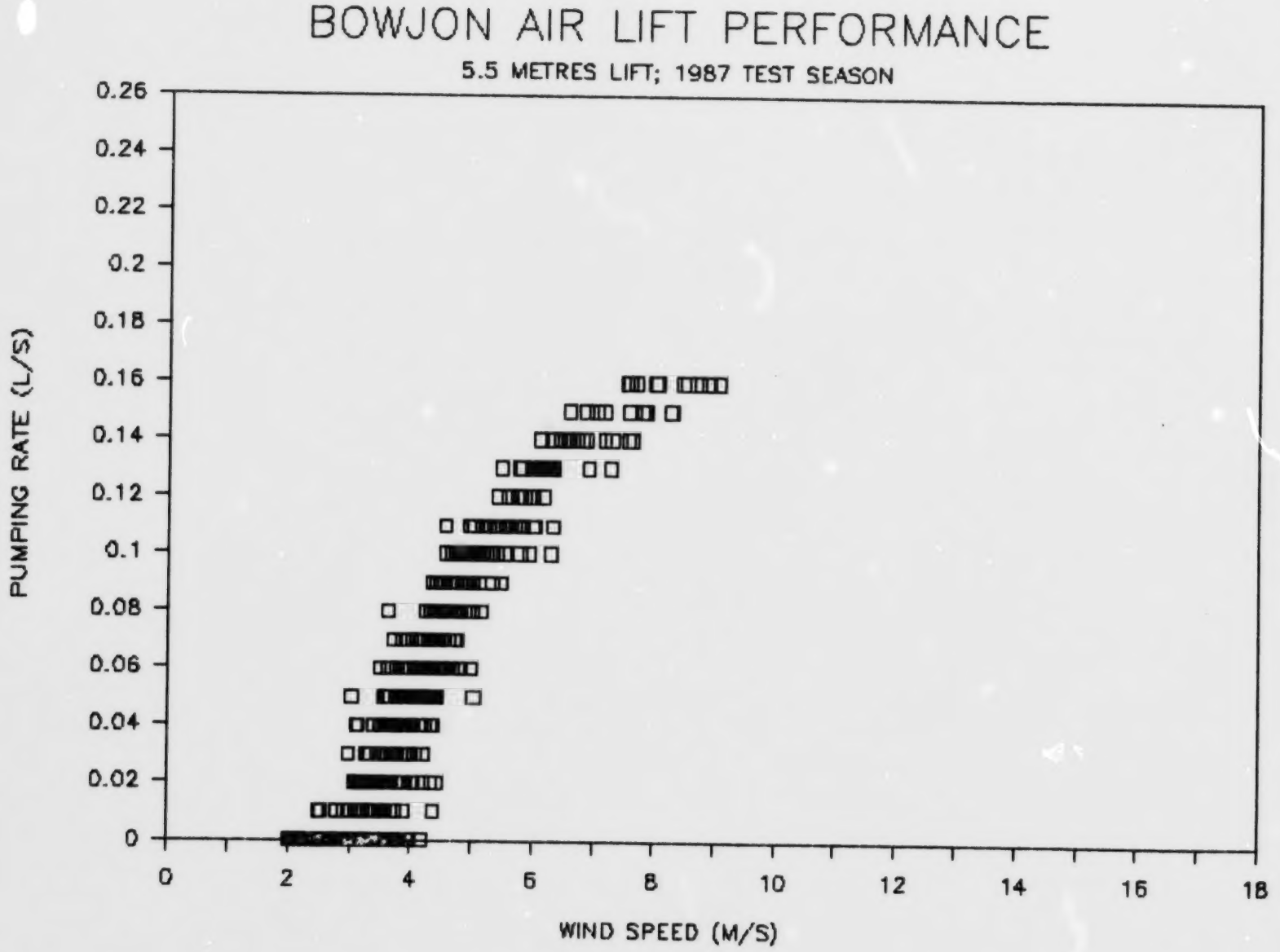
CHINOOK ROTOR PERFORMANCE

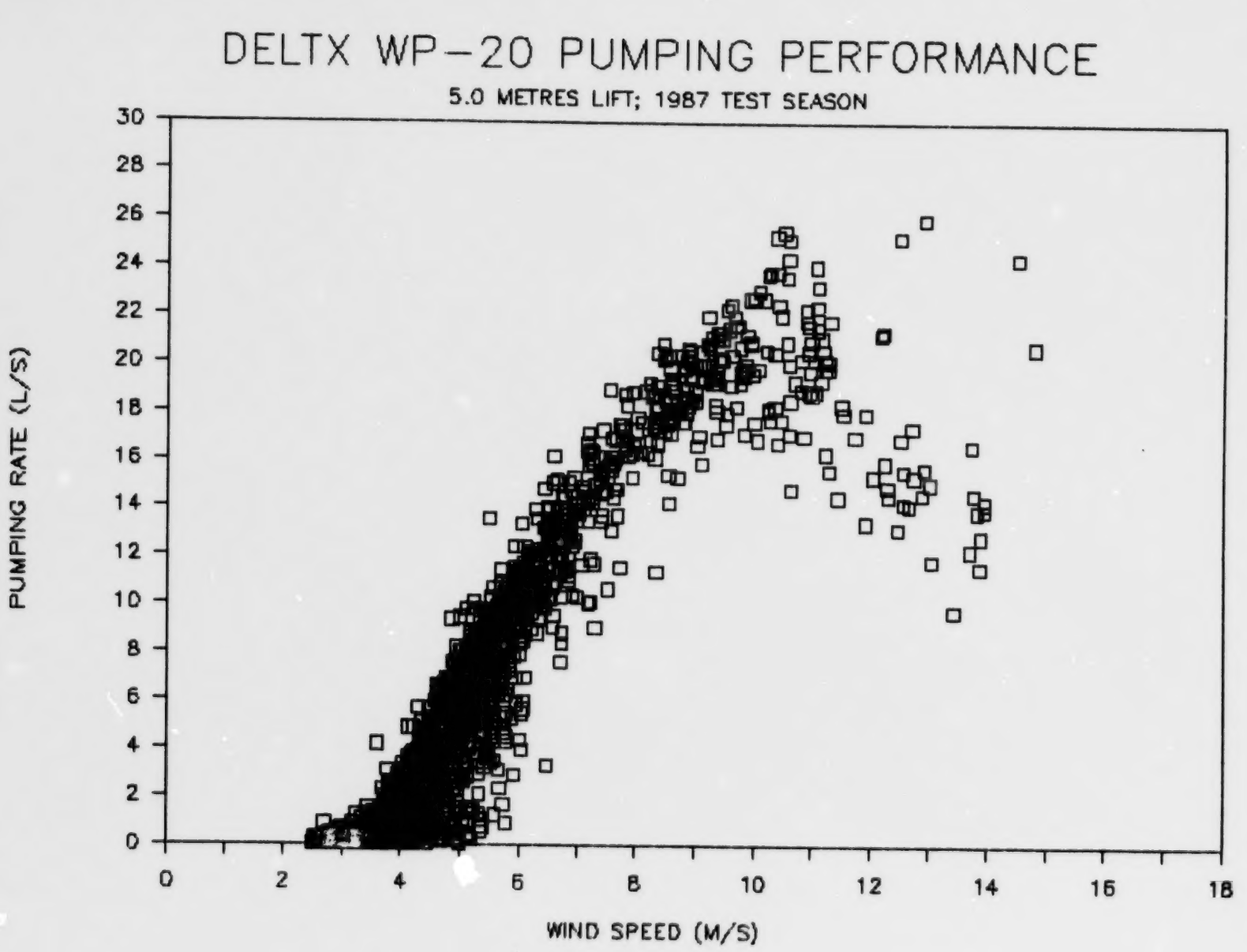
5.5 METRES LIFT; 1987 TEST SEASON




CHINOOK PUMP PERFORMANCE
5.5 METRES LIFT; 1987 TEST SEASON
PUMPING RATE (L/S)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
10
20
30
ROTOR SPEED (RPM)

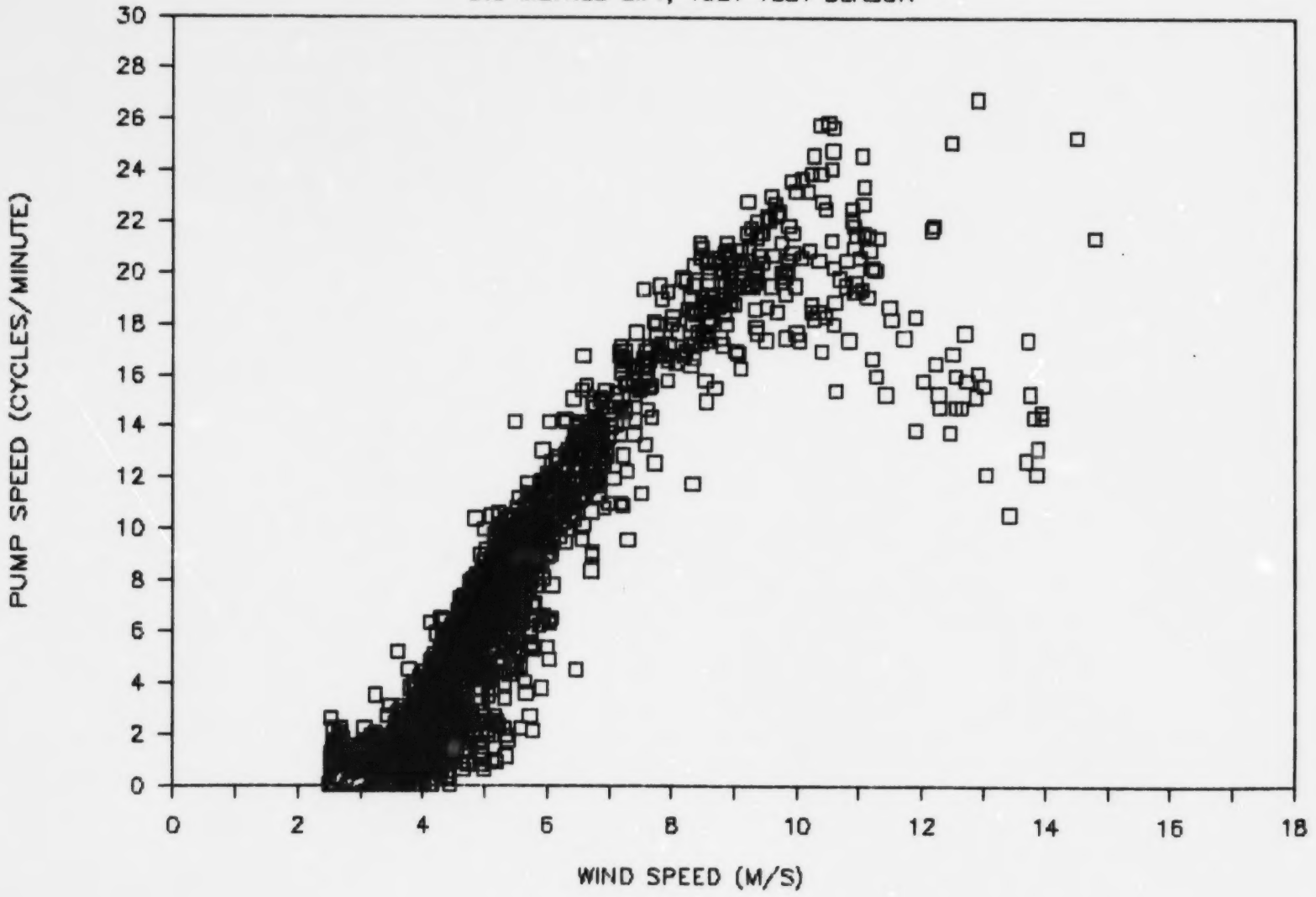

BOWJON DIAPHRAGM PERFORMANCE
5.5 METRES LIFT; 1987 TEST SEASON
PUMPING RATE (L/S)
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
2
4
6
8
10
12
14
16
18
WIND SPEED (M/S)


BOWJON AIR LIFT PERFORMANCE
5.5 METRES LIFT; 1987 TEST SEASON
PUMPING RATE (L/S)
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
2
4
6
8
10
12
14
16
18
WIND SPEED (M/S)


DELTX WP-20 PUMPING PERFORMANCE
5.0 METRES LIFT; 1987 TEST SEASON
PUMPING RATE (L/S)
WIND SPEED (M/S)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

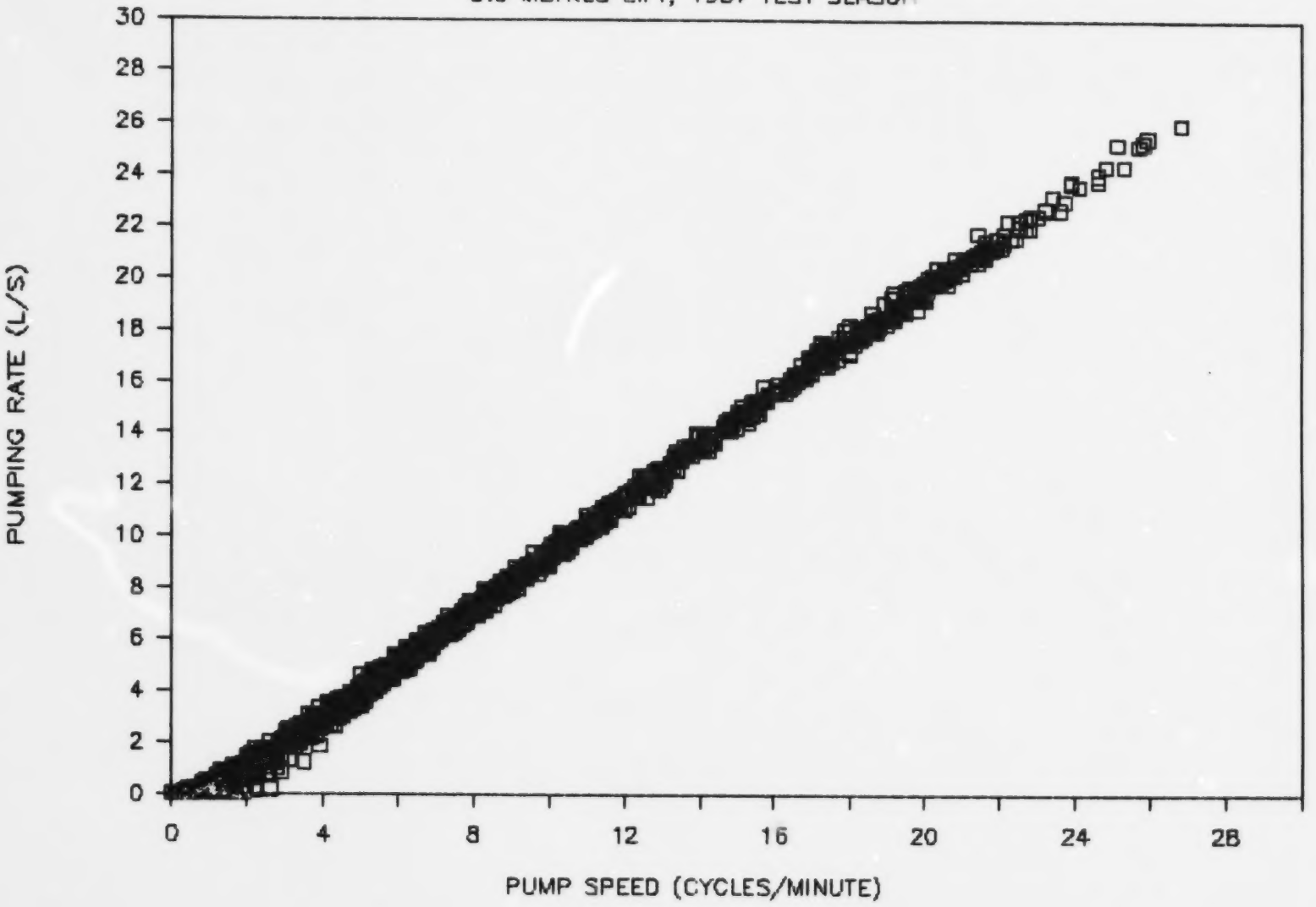
DELTX WP-20 PUMP CYCLE SPEED

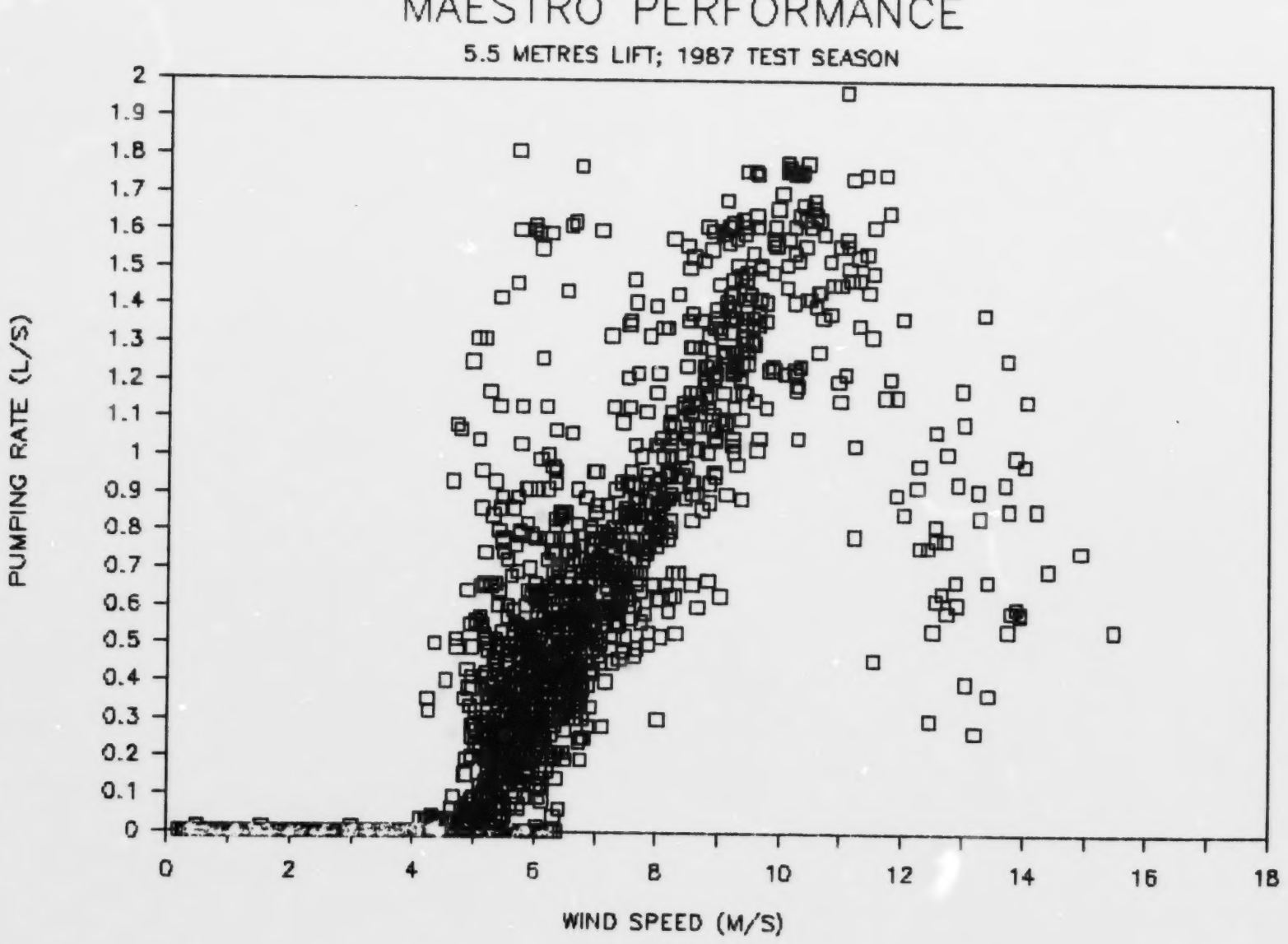
5.0 METRES LIFT; 1987 TEST SEASON

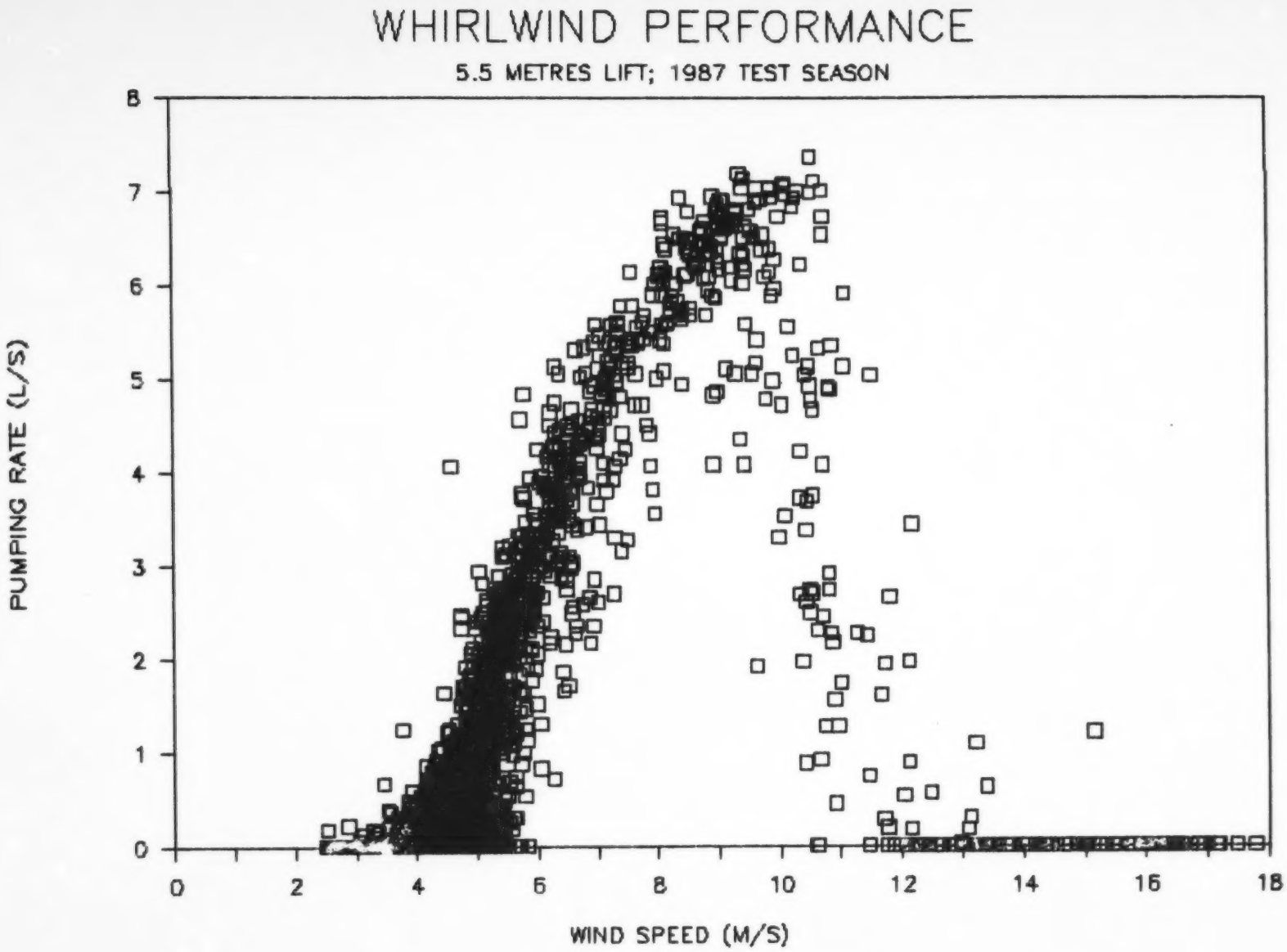


DELTX WP-20 PUMP PERFORMANCE

5.0 METRES LIFT; 1987 TEST SEASON

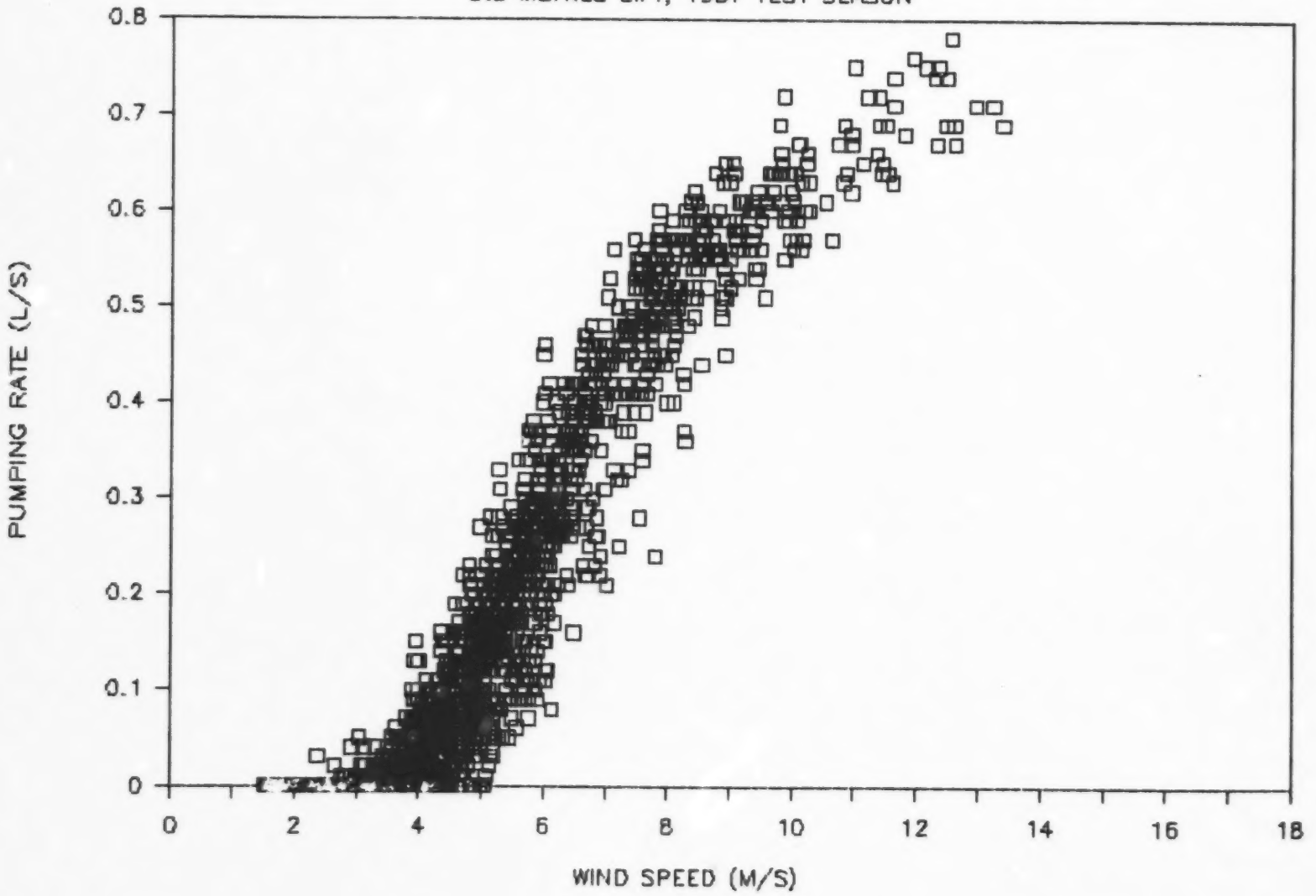



MAESTRO PERFORMANCE
5.5 METRES LIFT; 1987 TEST SEASON
PUMPING RATE (L/S)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
16
18
WIND SPEED (M/S)


WHIRLWIND PERFORMANCE
5.5 METRES LIFT; 1987 TEST SEASON
PUMPING RATE (L/S)
WIND SPEED (M/S)
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18

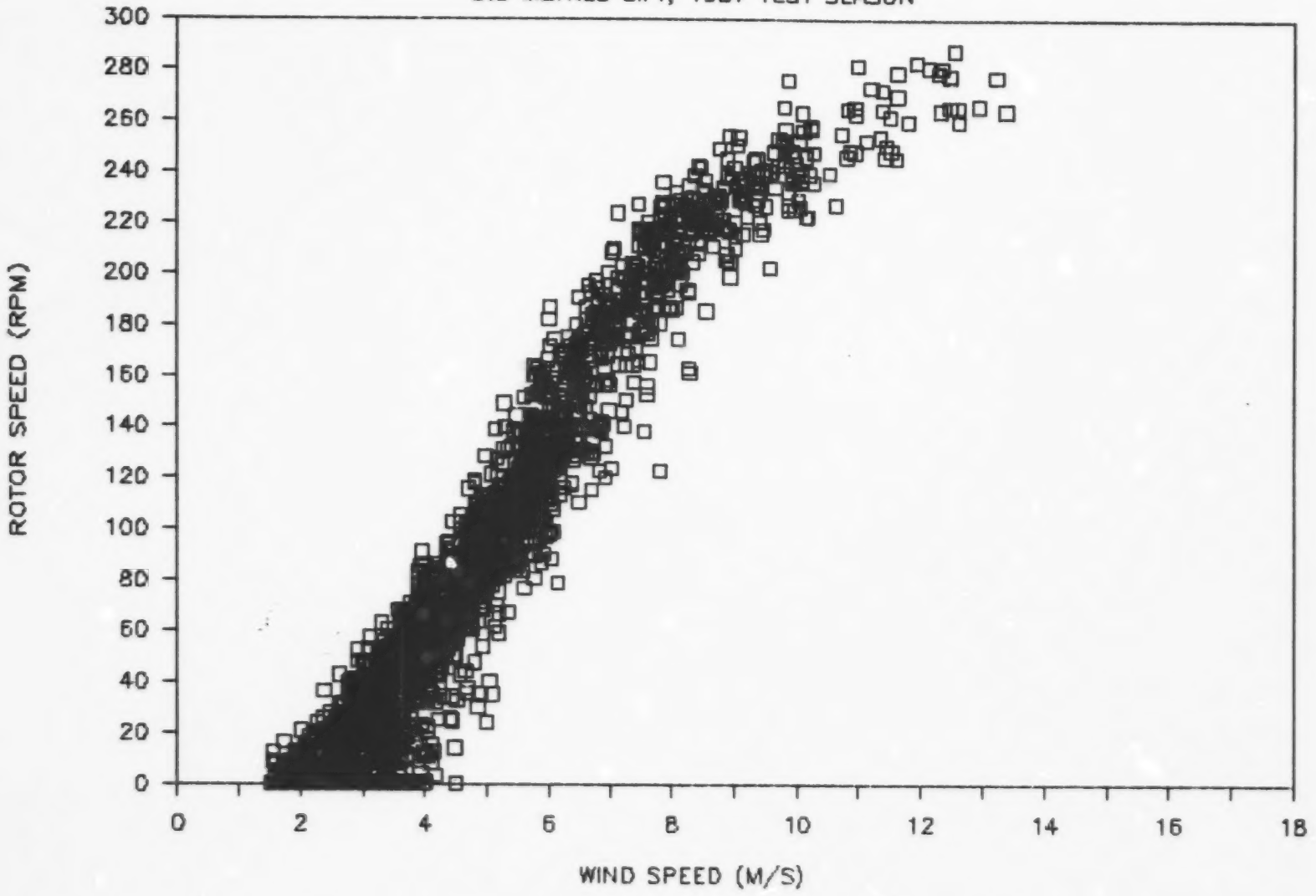
MAVERICK WINDMOTOR PUMPING PERFORMANCE

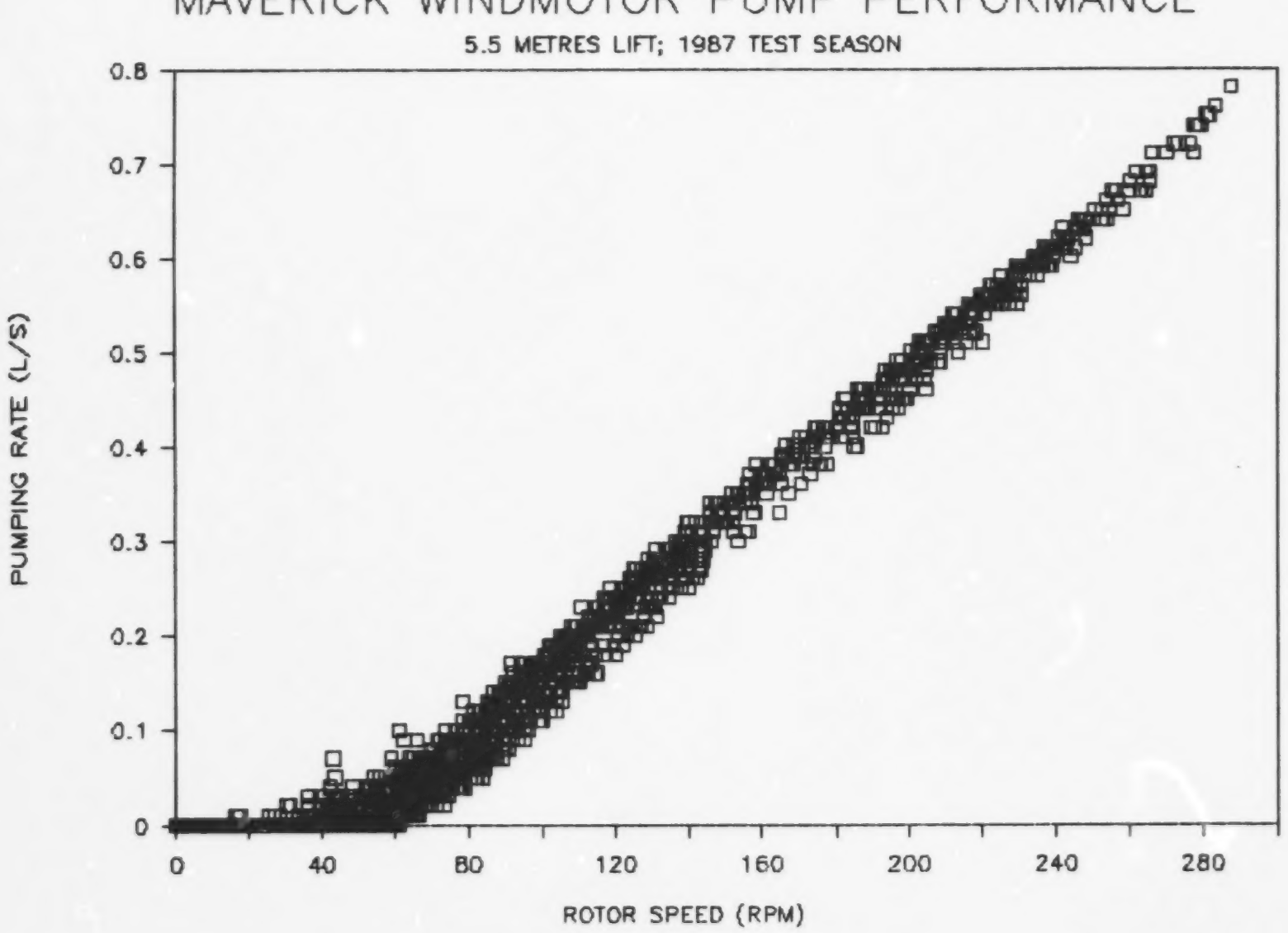
5.5 METRES LIFT; 1987 TEST SEASON



MAVERICK WINDMOTOR ROTOR PERFORMANCE

5.5 METRES LIFT; 1987 TEST SEASON




MAVERICK WINDMOTOR PUMP PERFORMANCE
5.5 METRES LIFT; 1987 TEST SEASON
PUMPING RATE (L/S)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
40
80
120
160
200
240
280
ROTOR SPEED (RPM)

APPENDIX "C"

RESULTS FROM PUMP TESTS PERFORMED BY PAMI

PL1887

PRAIRIE AGRICULTURAL MACHINERY INSTITUTE
c/o LCC Campus, Lethbridge, Alta., T1K 1L6 (403) 329-1212

9 February, 1988

Jensen Engineering
P.O. Box 1781
Olds, Alberta
T0M 1P0

Dear Eric:

Testing of the stainless steel lift pump was completed on the 22nd day of January, 1988. All test runs were done at the twelve inch stroke and with the neoprene leathers only. The pump was driven by an in-line slider crank mechanism powered by a five horsepower electric motor with a variable speed drive. Torque and rpm were recorded electronically, sampling at the rate of 8.3 samples per crank revolution. Flow and pressure were recorded manually. A Kent flowmeter as supplied by Dave Baker and an LC mechanical meter were both used. Test runs were made varying the rpm from 10 to 50 in increments of 10 and by simulating pumping heads of 50, 75, 100 and 125 feet.

Attached is the data summary sheet tabulating results from the various runs. Pressure as recorded electronically should be ignored as the readings were often erratic. Revolutions per minute recorded are average values but any fluctuations were minimal (less than 1%). Torque values are also averaged with the minimum and maximum values also tabulated. Horsepower calculations are based on the average rpm and the average torque readings. Flows are recorded in imperial gallons per minute and liters per second with the volumetric efficiency calculated based on a theoretical volumetric capacity of 1.273 gal (Imp.) per stroke. Pump efficiency curves were plotted with volumetric efficiency against pressure and rpm. The curves although not very consistent do seem to give rise to increased efficiencies at 30 rpm throughout the pressure range. The pump curve and the pump power curve show definite linear relationships between power, flow and pressure. Torque plotted against revolutions shows the torque variation within the twenty six cycles sampled. Peak pressure within a stroke was also recorded manually and the percentage overshoot was plotted against cycles per minute. Pressure overshoot increased with increasing rpm but generally decreased with increasing pumping heads. It should be noted that the singular point recorded at 40 rpm and all runs at 50 rpm were made using both vessles of pressure simulator whereas all previous runs were made using only the larger vessel. By operating with both vessels the peak pressure overshoot was substantially decreased.

The stainless steel casing lift pump was operated approximately 26 hours, accummulating 31,200 strokes ad pumping 37,750 gal (Imp.) of water. Wear in the stainless steel casing was negligible (less than .001 in diameter measurement) and the neoprene leathers had considerable life remaining.

Test runs on the PVC casing lift pump were started on February 7, 1988. Runs will be done similar to those done on the stainless steel pump but stroke length variations will be analyzed at 6, 8 and 12 inches. To date the PVC lift pump has accummulated 37,890 strokes and pumped 22,443 gal (Imp.). The volumetric efficiency works out to 96% based on a theoretical volumetric capacity of 0.618 gal (Imp.) per stroke. The durability evaluation will start immediately after the test runs are completed.

Further analysis of all data obtained will be done upon completion of the PVC lift pump tests, but in the meantime this information being sent to you should suffice as an interim report.

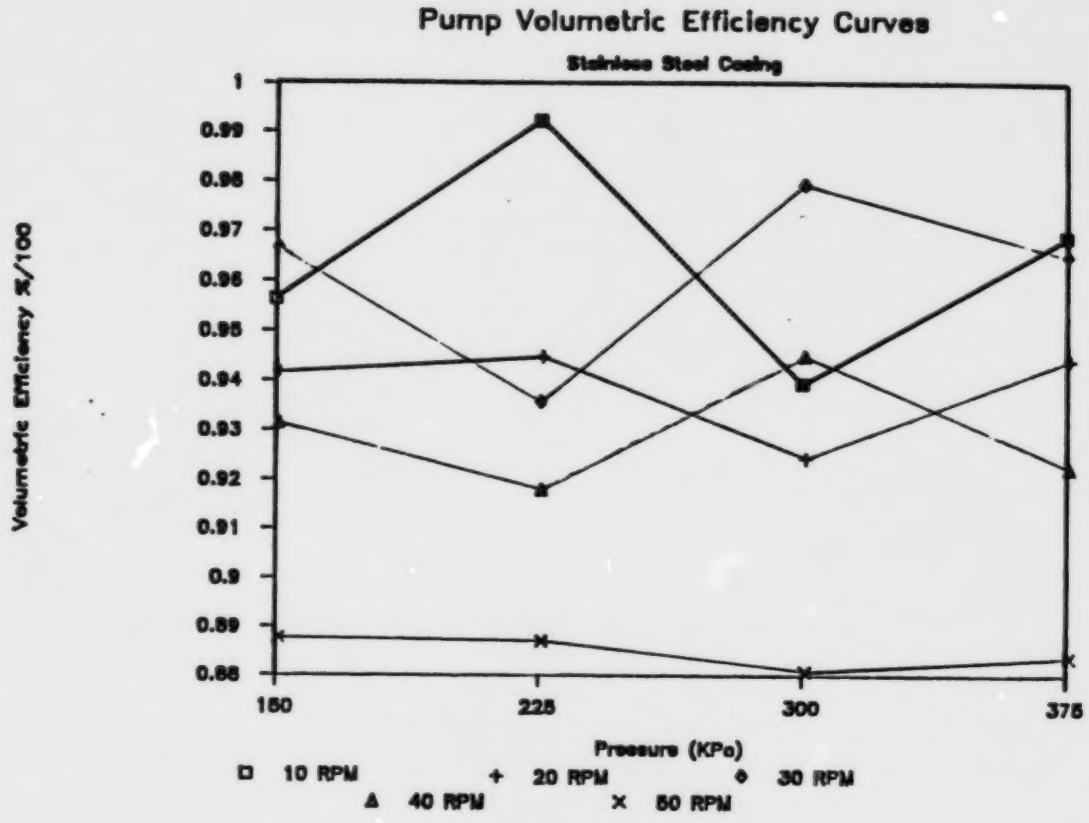
Sincerely,

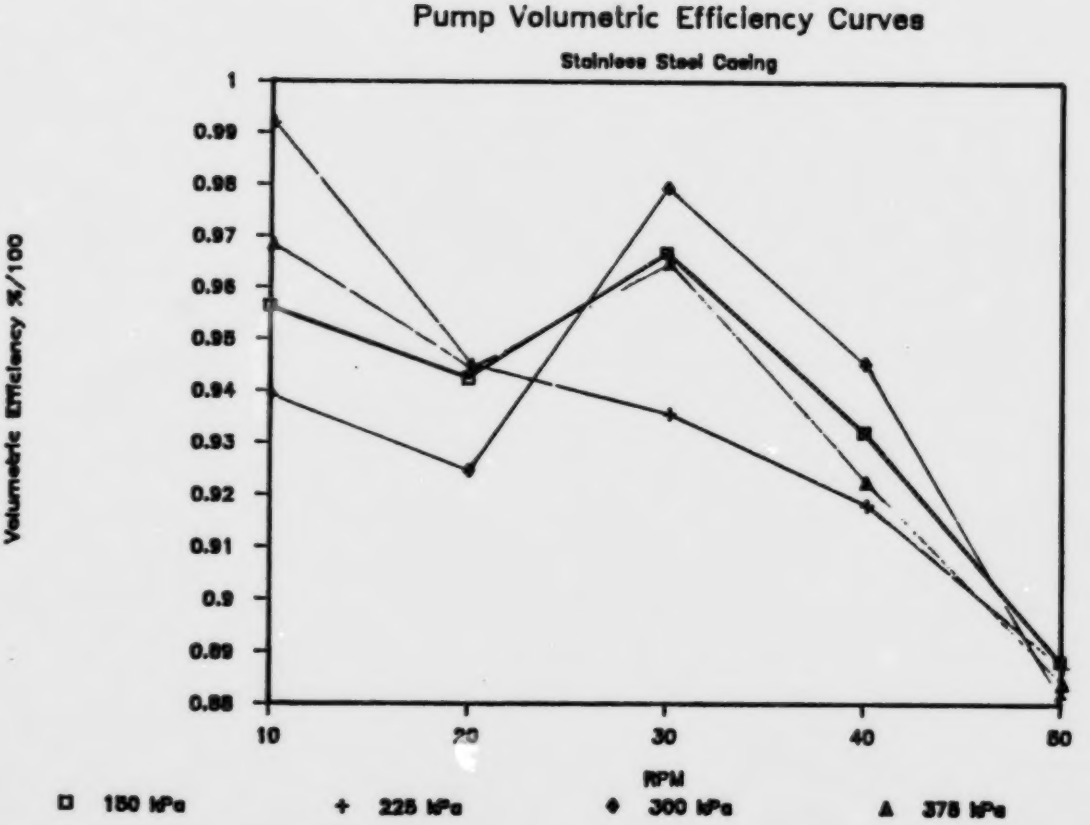
Richard Papworth
Project Engineer

/ag
Enc

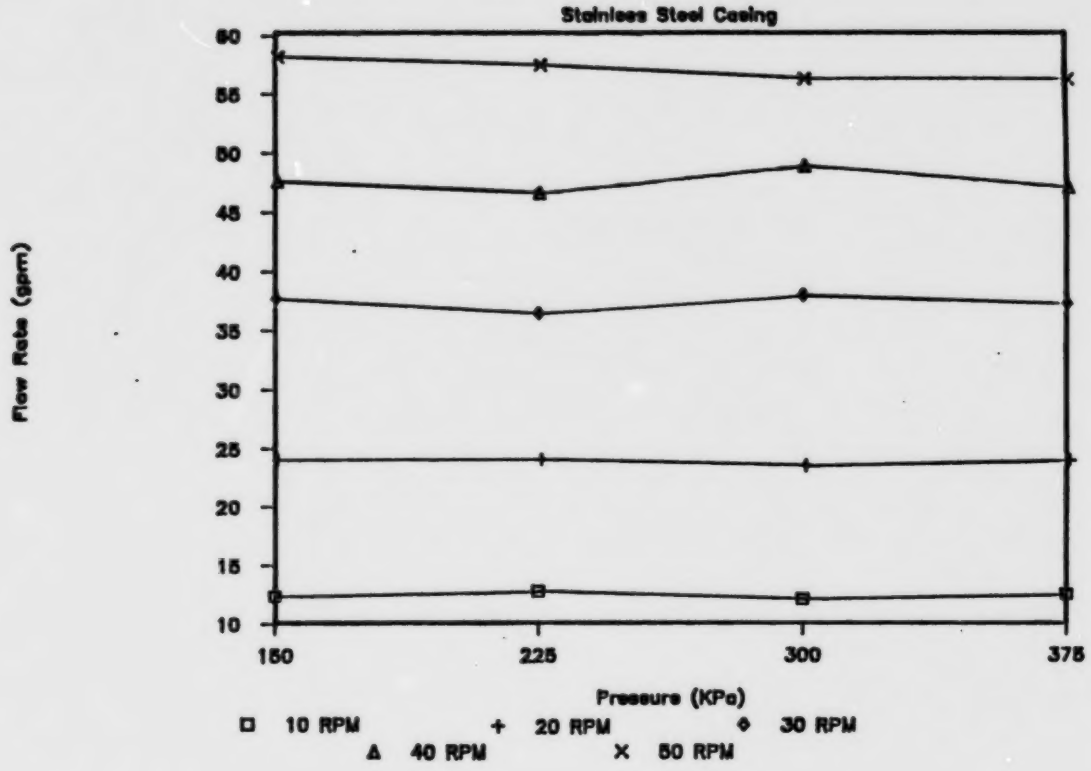
cc Rick Atkins

RUN:	Pressure (Set)	Pressure:	RPM:	Torque:	Tmin:	Tmax:	HP:	GPM:	L/sec	Vol. Eff.
P10-150	150	146.5941	10.17162	156.6732	-6.65	496.6	0.302432	12.38412	0.93702	0.956415
P10-225	225	224.4810	10.15446	215.2559	-16.55	684.7	0.413998	12.82848	0.97566	0.992406
P10-300	300	307.7940	10.14550	273.5902	-29.75	881.05	0.524800	12.13296	0.9177	0.939430
P10-375	375	384.0828	10.13407	329.9194	-41.3	1067.5	0.631766	12.50004	0.94668	0.968944
P20-150	150	144.9740	20.23592	169.2774	-0.05	569.2	0.647435	24.27558	1.8354	0.942362
P20-225	225	227.3196	20.19421	230.3236	-3.35	757.3	0.876256	24.30456	1.84506	0.945436
P20-300	298	304.7329	20.15152	289.4524	-11.6	927.25	1.095175	23.72496	1.79676	0.924845
P20-375	374	382.9392	20.08740	350.7621	-21.5	1108.75	1.317302	24.15966	1.82574	0.944797
P30-150	150	152.0741	30.74946	207.9187	4.9	714.4	1.195170	37.84788	2.86902	0.966886
P30-225	225	234.5353	30.68643	267.7312	1.6	892.6	1.526630	36.5631	2.77242	0.935983
P30-300	298	312.3440	30.53275	325.1718	-0.05	1057.6	1.831522	38.07972	2.88834	0.979714
P30-375	374	390.9267	30.39150	392.6805	-5	1247.35	2.185473	37.34556	2.83038	0.965291
P40-150	150	185.4962	40.34919	247.9770	3.25	895.9	1.856116	47.87496	3.6225	0.932062
P40-225	225	247.7673	40.06868	298.4879	-0.05	1055.95	2.204716	46.851	3.54522	0.910513
P40-300	298	334.3812	40.77023	375.1009	-3.35	1272.1	2.787429	49.0728	3.7191	0.945516
P40-375	374	408.9315	40.18117	435.7740	-8.3	1453.6	3.153361	47.20842	3.5742	0.922929
P50-150	150	192.6648	51.59302	259.6289	3.25	857.95	2.486040	58.33674	4.42428	0.888224
P50-225	225	258.1722	51.00925	314.1884	4.9	998.2	2.958444	57.63156	4.36632	0.887529
P50-300	298	328.4003	50.30754	369.9141	-0.05	1169.8	3.416070	56.44338	4.27938	0.881356
P50-375	374	405.3210	50.11992	435.6416	-3.35	1321.6	3.989567	56.42406	4.27938	0.884352

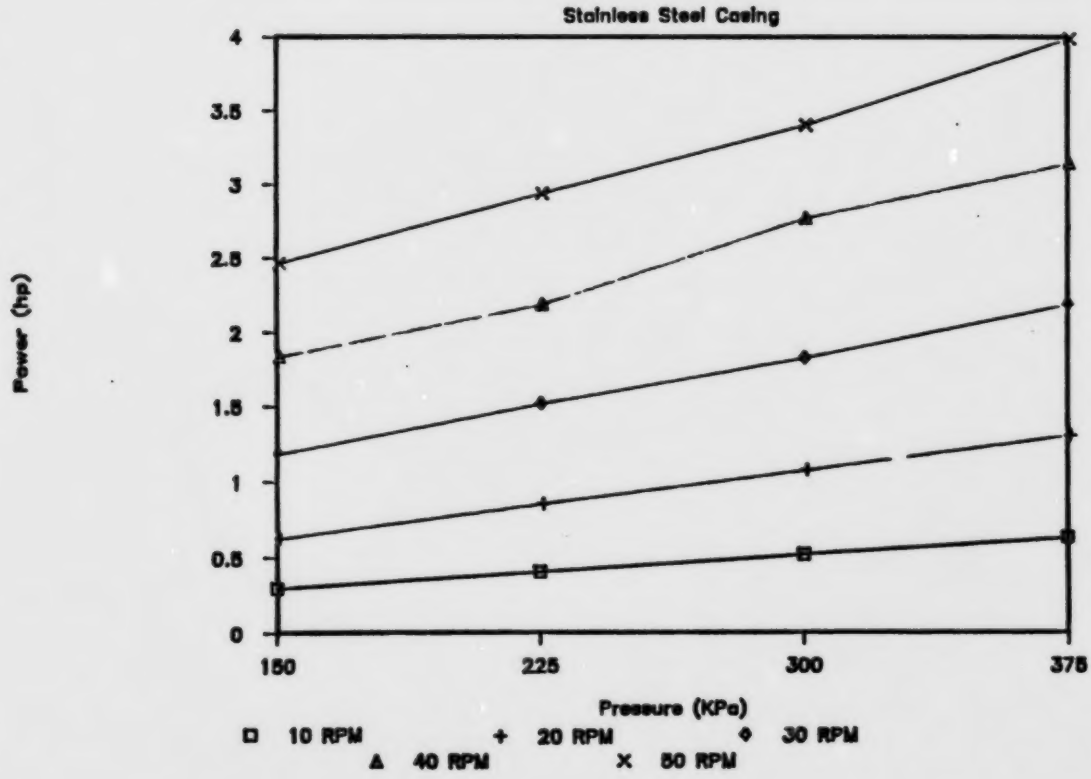

Pump Volumetric Efficiency Curves
Stainless Steel Casing
Volumetric Efficiency %/100
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.9
0.89
0.88
150
225
300
375
Pressure (KPa)
10 RPM
20 RPM
30 RPM
40 RPM
50 RPM


Pump Volumetric Efficiency Curves
Stainless Steel Casing
Volumetric Efficiency %/100
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.9
0.89
0.88
10
20
30
40
50
RPM
150 kPa
225 kPa
300 kPa
375 kPa

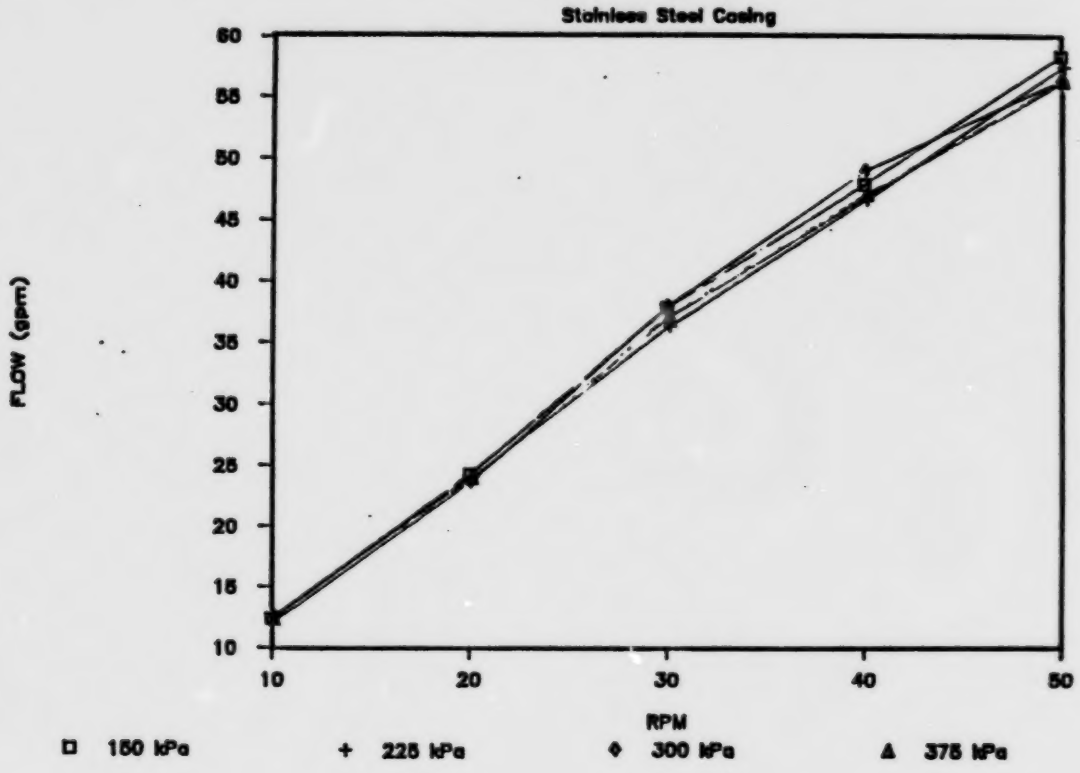
Pump Curves



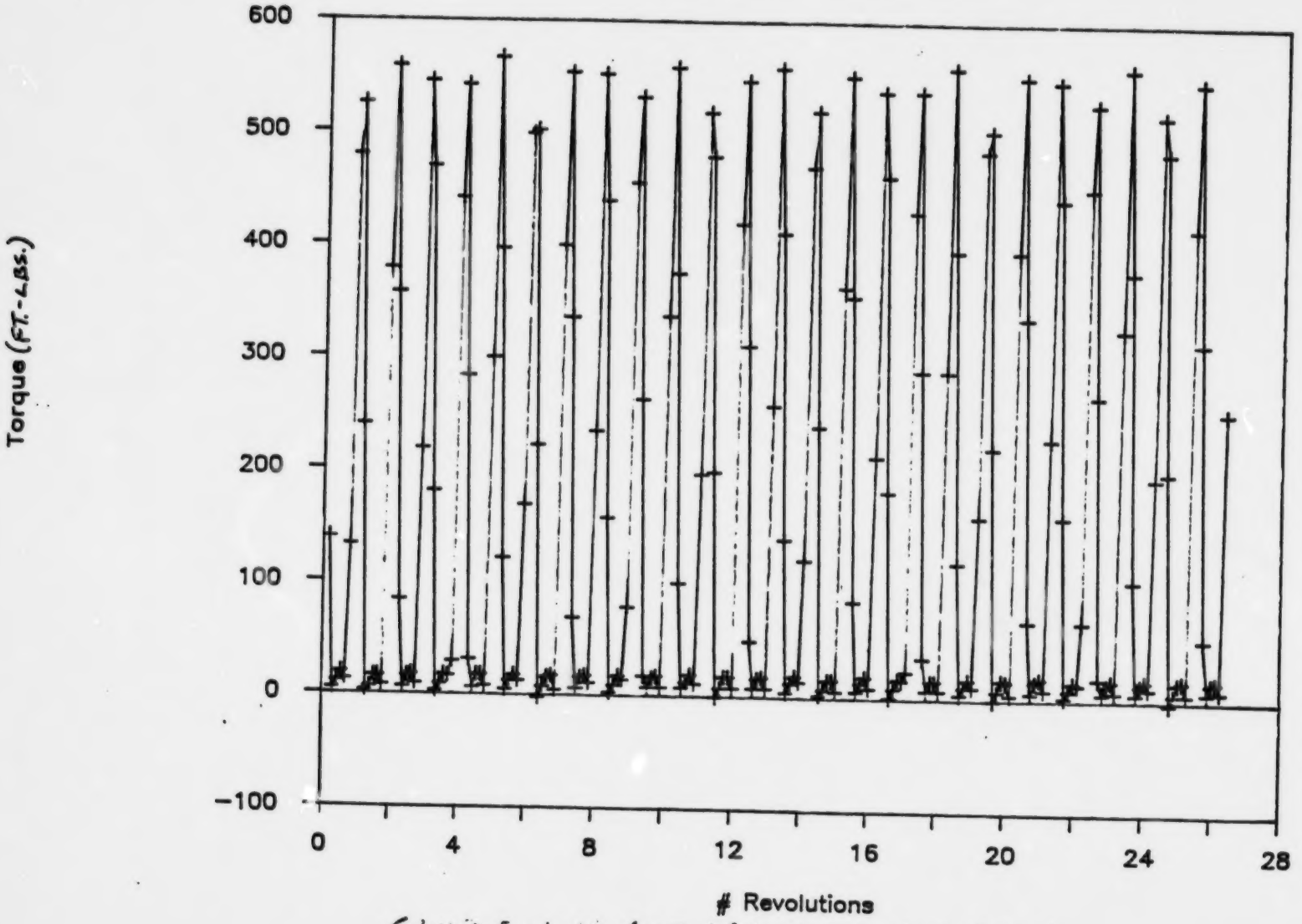
Pump Power Curves



PUMP FLOW CURVES



(50 FT. HEAD)



SINGLE X AVERAGE X SHAFT TIME

216